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JET PROPULSION LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY
PASADENA, CALIFORNIA

RE-ORDER NO. 62-824

EXP 387

26 February 1962

PENETROMETER

FINAL ACCEPTANCE TEST REPORT

URD 28, 29, 30 - Control Item X239235

TM-1330

TEXACO EXPERIMENT INCORPORATED
Richmond 2, Virginia

Submitted to

Jet Propulsion Laboratory

under Contract No. 950155

Contract NASW-6

950155

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RE-ORDER No 62-824

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THE PENETROMETER EXPERIMENT

This experiment was designed to determine the penetration resistance of the lunar surface material at three places by observation of the wave form of deceleration force measured by an accelerometer mounted on a small weight during impact of the weight upon the lunar surface. One such penetrometer device shall be dropped from each of the three spacecraft legs. The weight shall be caused to strike the lunar surface with a velocity of approximately 4 ft /sec. Two such instruments shall have hardened conical tips to accommodate the possibility of encountering hard rock. A third instrument shall have a hemispherical nose to provide improved resolution in the event that unconsolidated material of small grain size is encountered.

The accelerometers shall have adequate frequency-response characteristics to sense deceleration histories experienced during impact upon materials ranging from vacuum-sifted dust to hard, solid, strong, unweathered rocks such as fine-grained granite or quartzite.

By comparing the accelerometer wave forms obtained from the lunar experiments with wave forms obtained from laboratory experiments, the penetration-resistance property of the lunar-surface material shall be identified as equivalent to that exhibited by some type of earth material distinguishable from other types of earth material in terms of scratch hardness, compressive strength, and physical structure.

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THE PENETROMETER FINAL ACCEPTANCE TESTS

Purpose

The tests reported here were planned to indicate the ability of the prototype instrument to deliver the data required of it. These data will in turn require intelligent interpretation to serve its ultimate purpose, that of increasing the knowledge of the physical nature of the lunar surface.

The output of the instrument is a history of acceleration against time during the period of deceleration or penetration. Some of the items of useful information that may to some degree be obtained from this data are:

(1) pulse height, maximum or average, in units of acceleration;

(2) pulse width, in units of time;

(3) shape of curve, bounce, harmonics, etc.;

(4) rate of deceleration or slope, in units of acceleration per time; and

(5) velocity and displacement histories, achieved by integration of the curve.

The data reported here are concerned with the first two items.

Accuracy

There are two basic considerations of accuracy, absolute and comparative. All instruments and equipment used in getting numerical values must be carefully calibrated to insure that the absolute value read on the oscillogram is really 5.68 G's deceleration and not 5.63 G's, for example; these instruments include the accelerometers, amplifiers, and voltage-measuring devices. These procedures are quite straightforward except that we do not have the facilities for determining the voltage sensitivity of the accelerometers to the accuracy that the manufacturer can calibrate them.

Reproducible comparative data require that the test setup, the penetrometer tips, and the test sample be identical for successive drops. The latter has proven to be rather difficult. Natural rubber has shown itself to be superior to other materials, but some doubt has been expressed that this is a very good test since the material's yield point is not exceeded during the operation, and no material is permanently displaced. Uncompacted materials such as sand and pumice pack differently in each test because of difference in size and shape of the individual particles. The size and shape of the container affects the record and thus becomes an additional factor to control. The harder materials that yield to the penetrator point are affected by very minute surface differences since the drop energy is dissipated through a relatively small surface area. The fact that a new impact area must be presented to the penetrometer point for each drop adds to the problem, as does work hardening in metals and chipping or flaking in rocks.

A great deal of effort has been put into developing a test fixture that will exactly repeat itself. The base is leveled and weighted, the drop position pinned, the arm pivoted on a Mylar flexure and carefully balanced in the suspended position, and the penetrometer released by withdrawing a pin.

Experience continues to uncover procedures that may be contributing to the scatter of test data. As experience is gained the operator and instrument errors can be expected to diminish, but the point may have already been reached where the test material is being tested for homogeneity rather than the penetrometer devices for reproducibility.

Equipment

The following equipment is actually used to perform the tests:

(1) Penetrometers 387-241-0A and 387-242-0A which include Endevco Corp. Model 2233 M-11 accelerometer.

(2) Test fixture, TEI 387-465-0A, and necessary test samples.

(3) Test box, TEI 387-442-01, which includes Endevco Corp. Model 2620 charge amplifier.

(4) Oscilloscope, Tektronix 535 with Type L Plug-in unit.

(5) Oscilloscope camera, Polaroid with Type 146-6 film.

(6) Hot and cold oven, Delta 1060W (for variable temperature tests).

(7) Vacuum chamber, 2 ft in diameter by 3 ft long, shop made, with Kinney KMB 230 pump.

To calibrate the scope vertical deflection, the following additional equipment is used:

(1) Signal generator, Hathaway, Model N-2.

(2) AC Voltmeter, Ballantine, Model 317.

(3) Converter, AC to DC, Ballantine, Model 710.

(4) Potentiometer, L and N, Type K-2.

(5) Standard cell, Epply, Cat. No. 103.

(6) Galvanometer, L and N, Cat. No. 2430.

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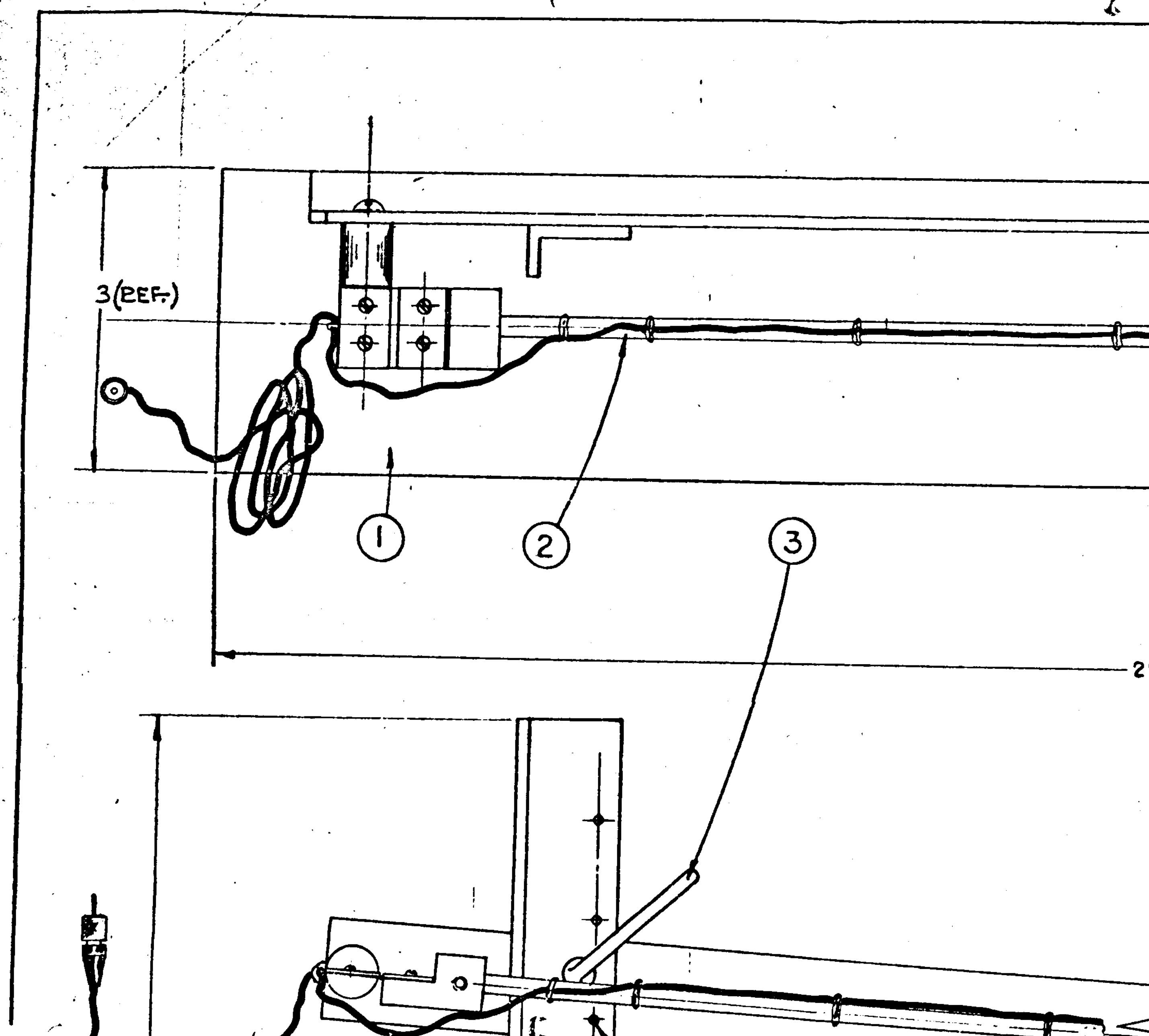

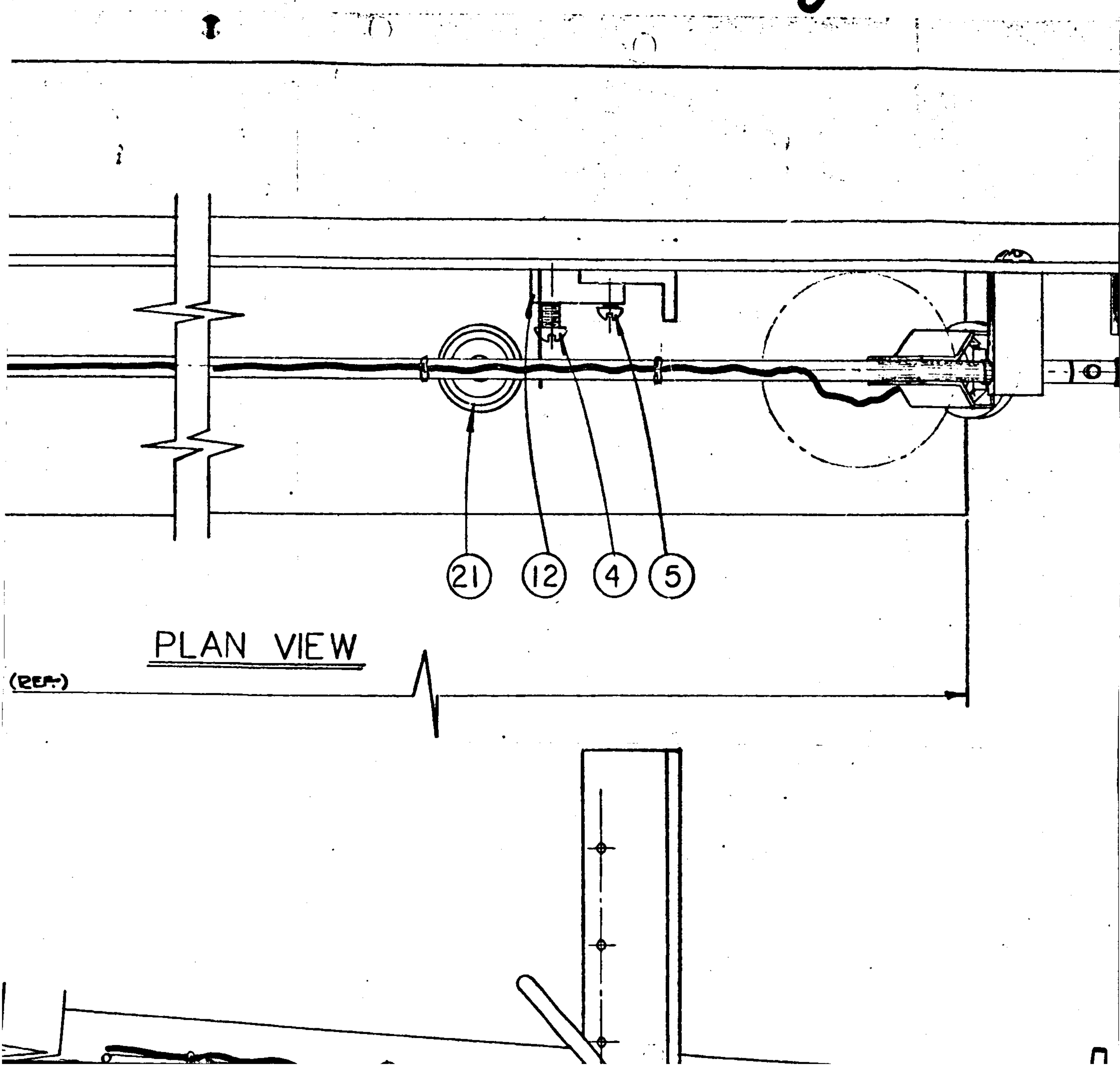
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PLAN VIEW
(REF.)

RE-ORDER No. 65-824

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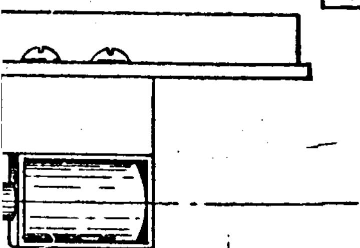
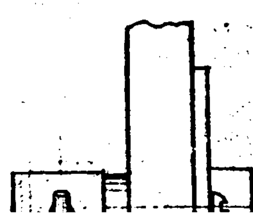
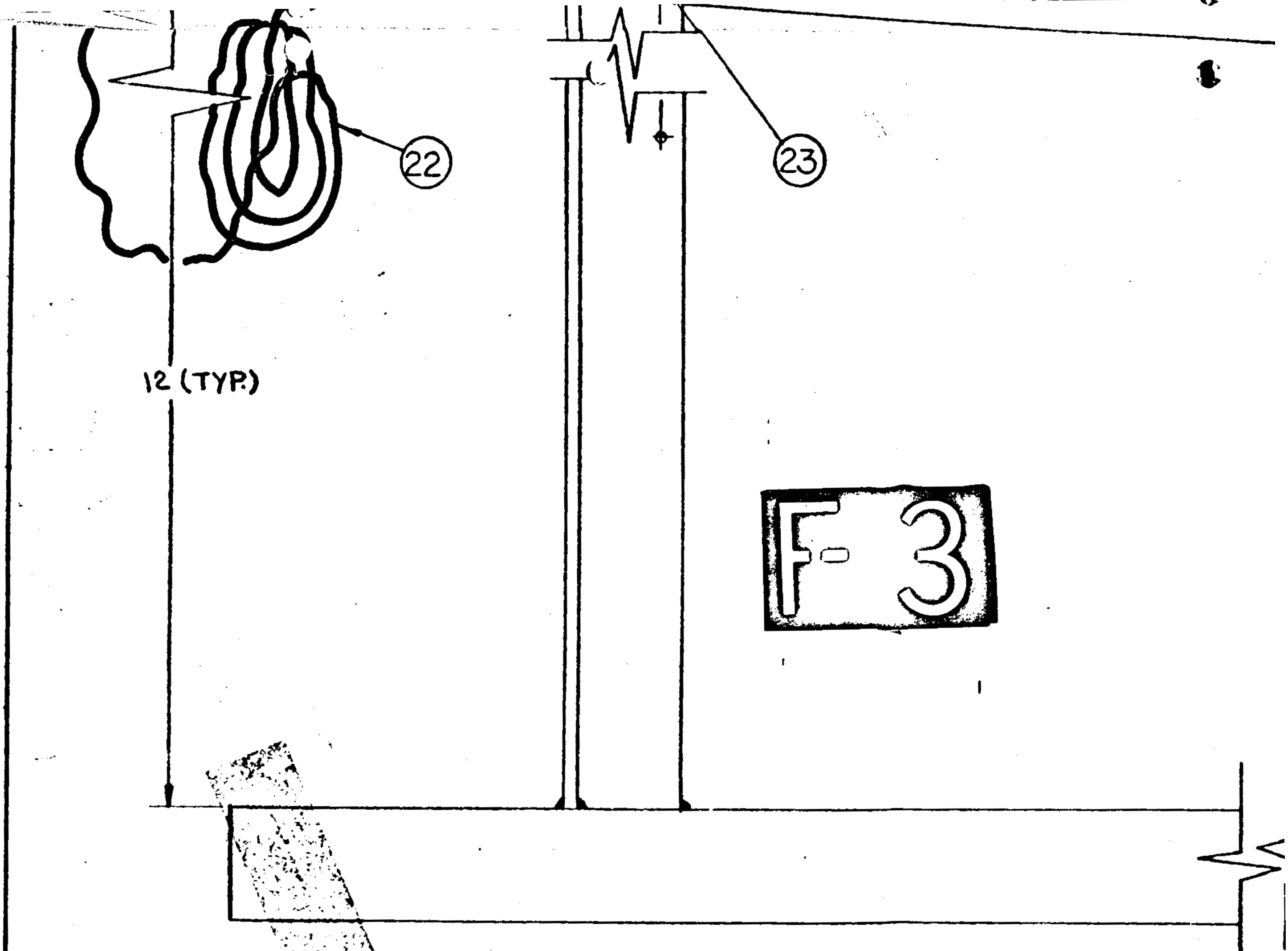


LIST OF MATERIAL

ITEM	REQD	PART NO.	DESCRIPTION
1	1	387-465-00-02	BASE
2	1	387-465-02	ARM ASSEMBLY
3	2		1 IN. "C" CLAMP
4	1	STEEL	RD. HD. MACH. SCR. 10-32UNF-2A THD. x 1 LG.
5	2	STEEL	RD. HD. MACH. SCR. 8-32UNF 2A THD. x 5/16 LG.
6	1	FORM TO SUIT	SPRING-MUSIC WIRE-.025 DIA. x A LG.
7	1	387-463-00-01	TRIGGER PLATE
8	1	STEEL	RD. HD. MACH. SCR. - 8-32 UNF 2A THD. x 3/8 LG.
9	2	STEEL	RD. HD. MACH. SCR. - 4-40 UNC 2A THD. x 3/8 LG.
10	1	387-241-0M	PENETROMETER - OUTLINE & MTG.
11	1	387-465-03-01	ANVIL
12	1	387-463-00-04	TRIGGER BLOCK
13	1	STEEL	WASHER PLATE - 7/16 I.D. x 1/2 O.D. x 1/16 THK.
14	1	STEEL	RD. HD. MACH. SCR. - 10-32 UNF 2A THD. x 7/16 LG.
15	1	387-465-03-02	ANVIL
16	1	387-465-03-03	
17	1	387-465-03-04	
18	1	387-465-03-05	
19	1	387-465-03-06	
20	1	387-465-04	ANVIL
21	1		BUBBLE LEVEL - EMPIRE CORP.
22	1		WIRE ASSY. - ENDEVCO #3090-120
23	2	387-465-00-03	PIN
24	1	387-465-03-07	ANVIL





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NOTES:
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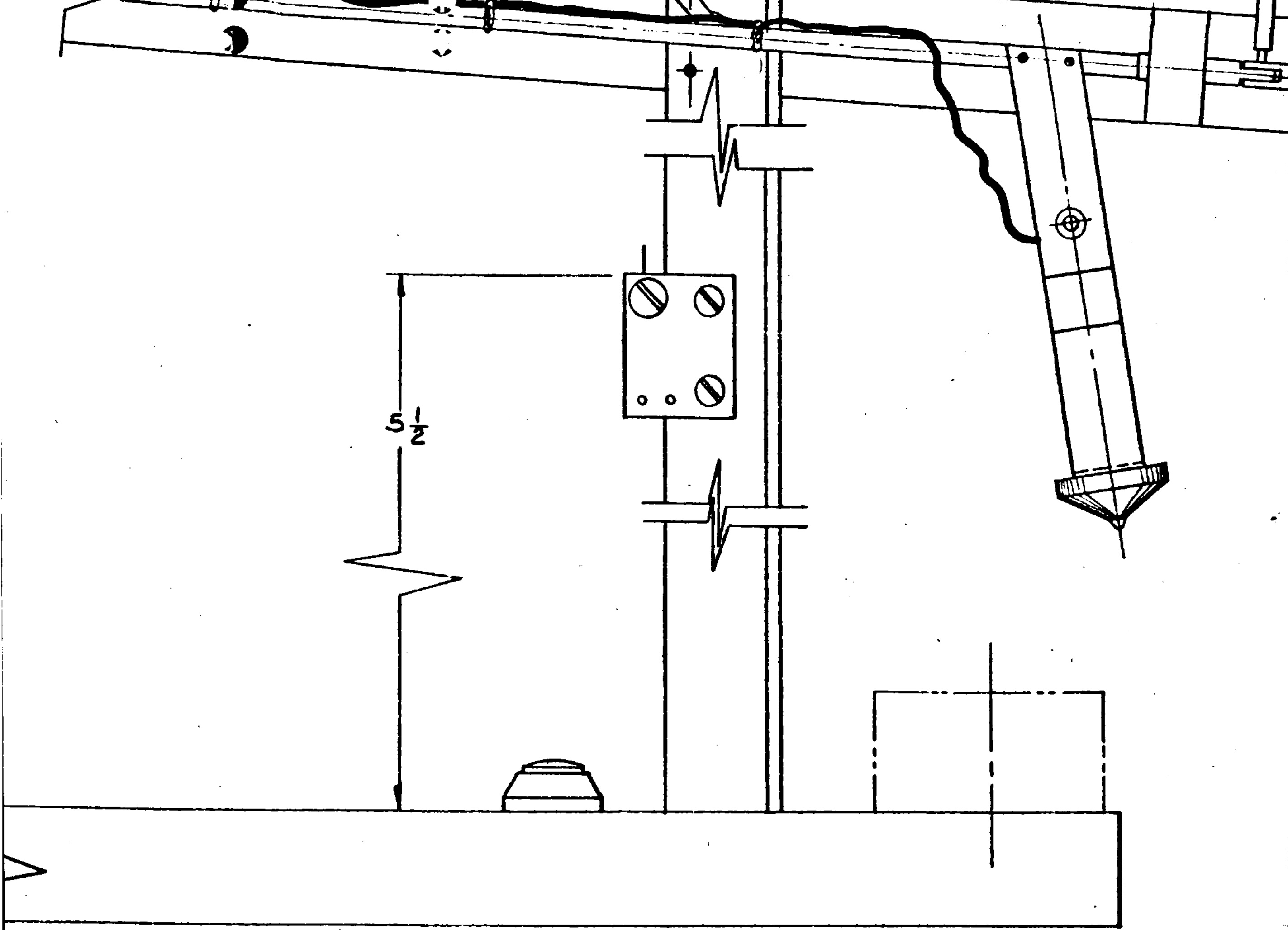

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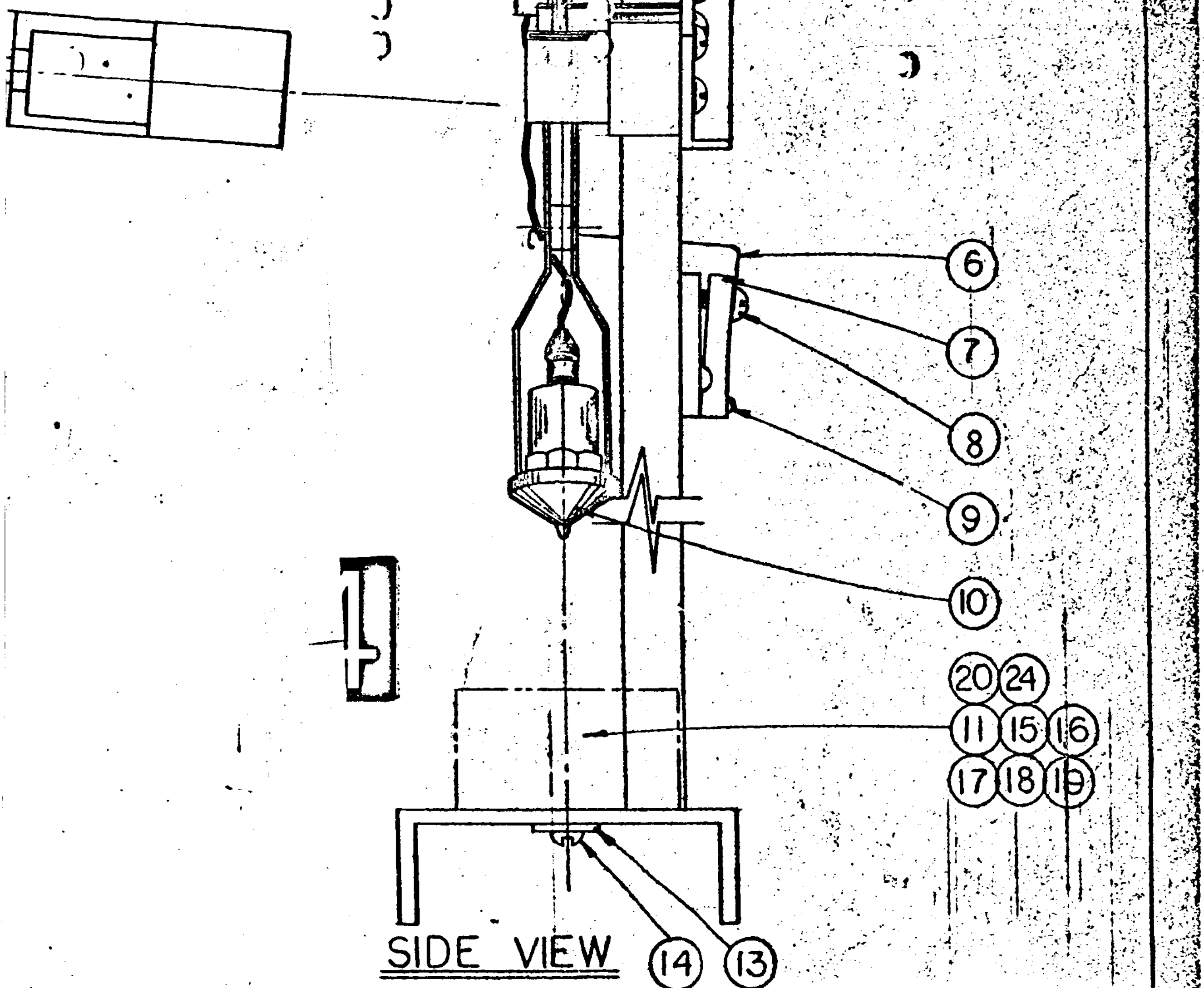

SIDE VIEW

NO.	DATE	NATURE OF CH...
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UNLESS OTHERWISE SPECIFIED:
ALL DIMENSIONS IN INCHES.
ALL TOLERANCES:
DECIMAL ± .010 ANGULAR ± 1°
FRACTIONAL ± 1/64

1 REQ.D.

TEXACO EXPERIMENT INCORPORATED
RICHMOND, VIRGINIA

PENETROMETER
TEST FIXTURE ASSY.

DRAWN S. BROUDE ENGR. V.M.B.
CHECKED EBH APPROVED
SCALE FULL DATE 2-15-...

387-465-0A

686

Procedure

In order to get a trace of maximum usable size on the scope a scope-voltage calibration must be used that is not available internally. With recently calibrated equipment, the following steps are taken in preparation to testing:

(1) Observe several test drops on the scope and adjust the scope gain to get a trace that approximately fills the vertical grid space.

(2) Without changing the scope gain connect a signal generator in place of the penetrometer and adjust the signal generator output to get a trace that approximately fills the vertical grid space.

(3) With an accurate ac voltmeter increase the signal-generator output to the next scale calibration mark on the voltmeter (because the voltage can be more accurately reset to a line) and readjust the scope gain to get a trace that exactly fills the vertical grid space (6 cm in these tests).

(4) Without changing the signal generator output, check the voltmeter reading with a converter, standard cell, and potentiometer. This is the rms value of the 6-cm peak-to-peak trace on the scope. When this same calibration voltage is repeated, it need not be rechecked by comparison to the standard cell since the stability rather than absolute value is being used. This is usually quite accurate; e.g., in the instrument used in these tests the stability is 0.2% against an absolute accuracy of 2%.

(5) Without changing the scope gain disconnect the signal generator, reconnect the penetrometer, and set the trigger and sweep by observing test drops.

After the test drops are recorded, the calibration voltage can be applied to the scope and observed to assure that the scope gain has not been accidently changed.

All drops were released by hand except in the vacuum-chamber tests, where release was effected by a solenoid.

Great care must be taken with the material test samples. The following points are noted:

(1) Any container of loose particles must be sifted or otherwise loosened after each test and repositioned carefully, since the proximity of the container walls can affect the results.

(2) The level in the container of loose particles must be held constant. Additions must be made for splash-out or drag-out.

(3) Permanently deformed materials must be repositioned after each test to present a new impact area to the penetrometer. Rotation of the material to give a circular drop pattern is preferred on the metal samples since they are cut from bar stock and hardness gradients tend to be greatest in a radial direction.

(4) With the harder materials it appears that the hold down force or degree of restraint or mass of the test sample affects the results noticeably, as will be mentioned in the discussion of the comparison of drops on mild steel. Probably the natural frequency of the material or anvil portion of the test fixture should be lowered as much as possible.

(5) When the hot and cold runs are being made, the penetrometer must not be allowed to remain on the gum-rubber test sample since it might change the temperature of the sample and the results of the next run.

(6) The cone tip must be inspected often when used on hard or abrasive materials.

The curves are recorded reduced 2.5 times on Polaroid transparencies, two traces per slide, and then enlarged to scope size on Mylar negatives. A 6x comparator is used to read the full-size reproductions to 0.1 mm. Where a curve contains high frequency "hash," an average value is used; e.e., a smooth curve is drawn through the trace and measurements taken from this. The point of departure from the base line is determined by drawing the best straight line through the first half centimeter of deflection.

Results

Man-made materials

Figures 1 through 16 represent the tests on a range of man-made materials that goes from approximately 10 to 2500 earth G's. The tests represented by Figures 7-14 are repeated on two other accelerometers for comparison purposes.

Note that on urethane foam the spherical tip gives lower G values but greater pulse width than the conical tip.

The internal scope-calibration voltage is used on tool steel since the signal generator output is insufficient. Scope accuracy is $\pm$ 3%. The nature of the curve in this case makes it impractical to read the curve even that close, however.

It can be seen in Figures 15 and 16 that the amplifier clipped the output signal. The accelerometer was initially desensitized by means of a series attenuating capacitor until the output could be handled by the charge amplifier without clipping. Evidently changes have been made during development that have raised the G level of all results, probably caused by the increased restraint of the test samples.

Device No. ____________   Vert. Sens. = .4714 RMS Cal. Voltage   System E_s = C_t x E_s x 2.4 x 10^{-3} mv/G

Accel. Ser. No. DA58   = 2.48 mv/G

Accel. E_s 34.0 peak mv/peak G   Date 1/29/62-2/6/62   Scope G Sens. = Vert. Sens. ÷ System E_s

Circuit C_t 30.4 pf (measured)   Observer W. L. Hall   Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Temp. °C	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
1 2	Urethane Foam	3	Room		x	15.00	7.071	2.851	5.0	4.23 4.37	2.97 3.16	12.1 12.5	14.9 15.8		
3 4	Urethane Foam	3	Room	x		15.00	7.071	2.851	5.0	3.41 3.48	3.53 3.55	9.72 9.92	17.7 17.8		
5 6	Gum Rubber	3	Room		x	36.00	16.97	6.843	1.0	6.21 6.10	7.99 8.05	42.5 41.7	7.99 8.05		
7 8	Gum Rubber	3	Room	x		53.95	25.43	10.25	1.0	6.07 6.11	4.84 4.83	62.2 62.6	4.84 4.83		
9 10	Lead	3	Room		x	129.8	61.19	24.67	.2	6.34 6.22	5.28 5.03	156 154	1.06 1.01		
11 12	Aluminum	3	Room		x	277.3	130.7	52.71	.1	6.14 6.16	4.42 4.37	324 325	.442 .437		
13 14	Mild Steel	3	Room		x	599.5	282.6	114.0	.05	6.59 6.55	4.35 4.32	751 747	.218 .216		
15 16	Tool Steel	3	Room		x	-----	1000	403.2	.05	6 6	3.6 3.1	2400 2400	.18 .16		

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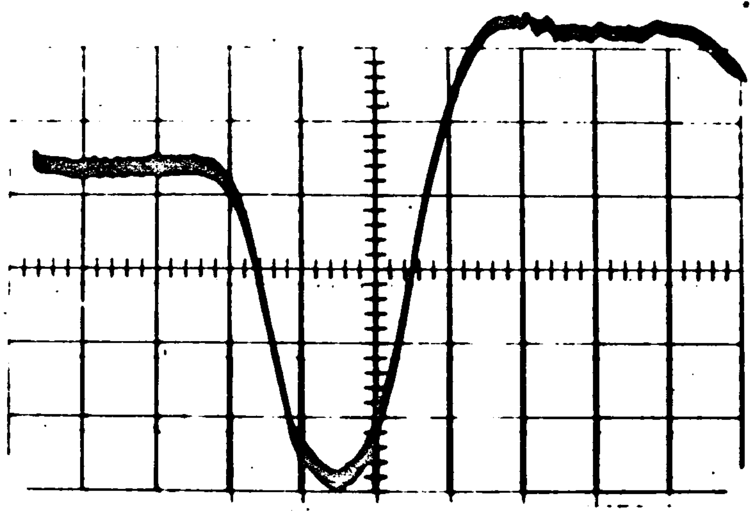

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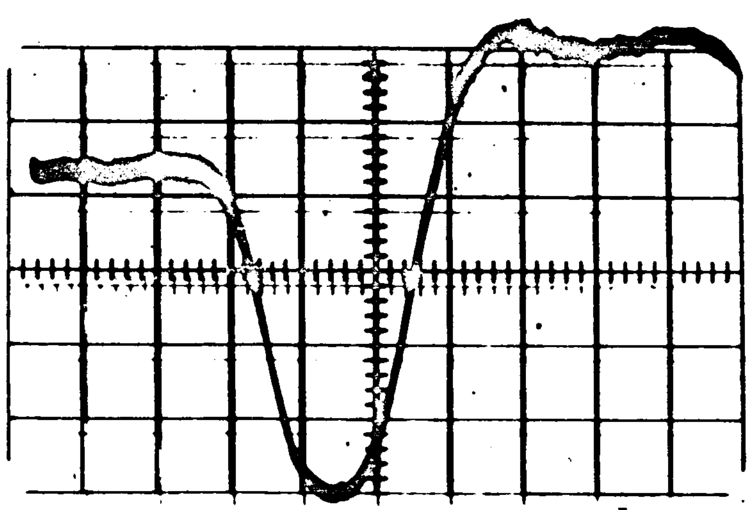

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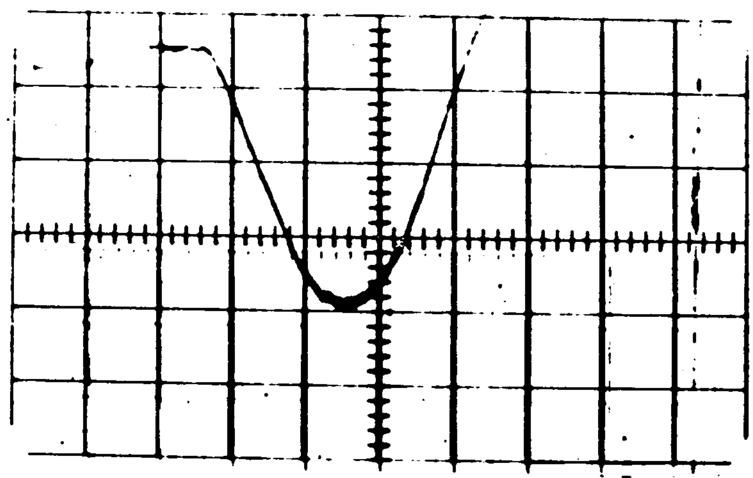

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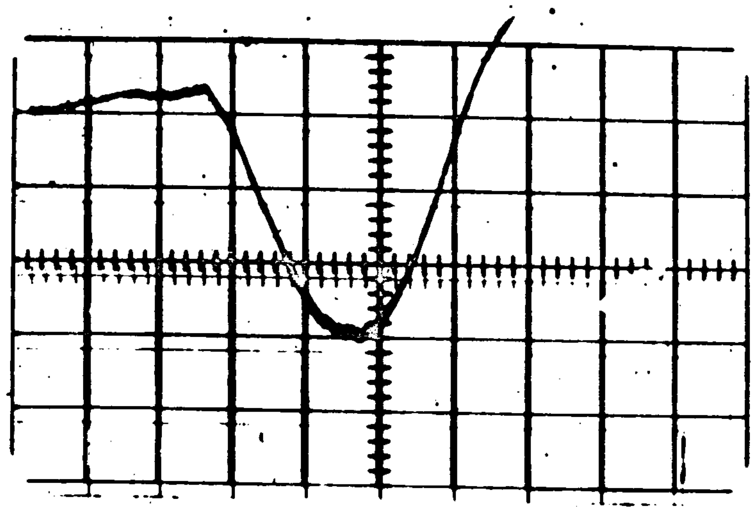

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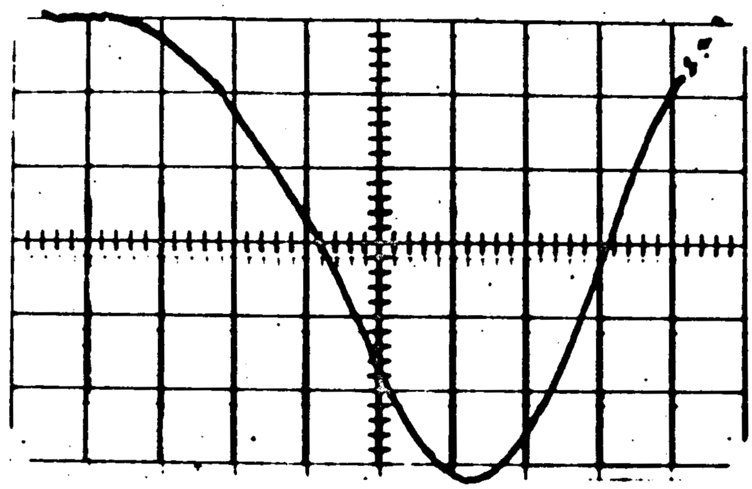

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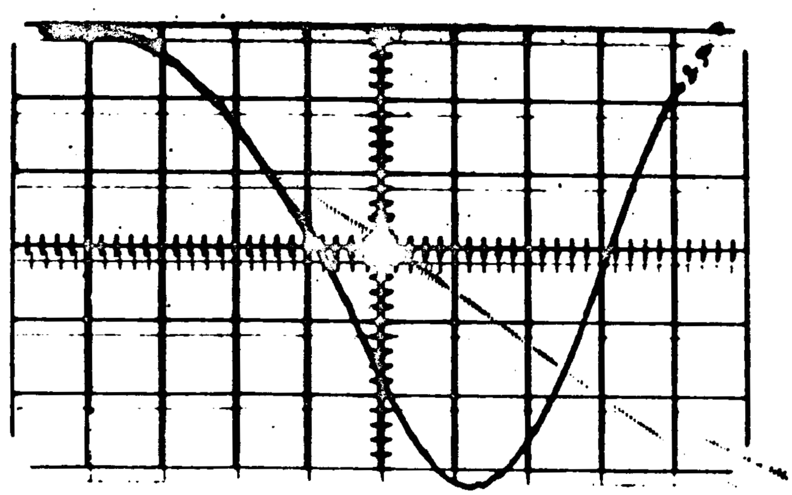

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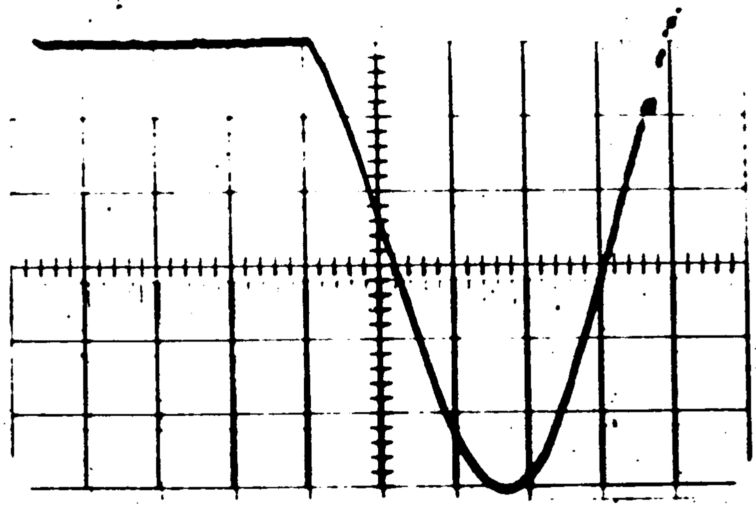

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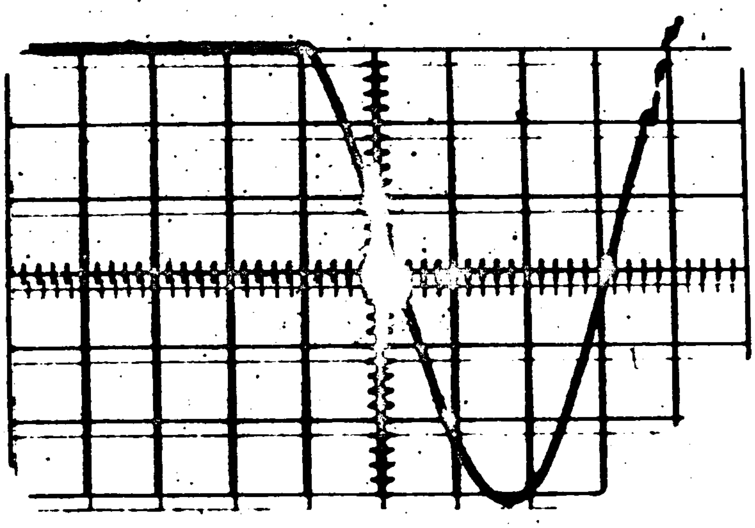

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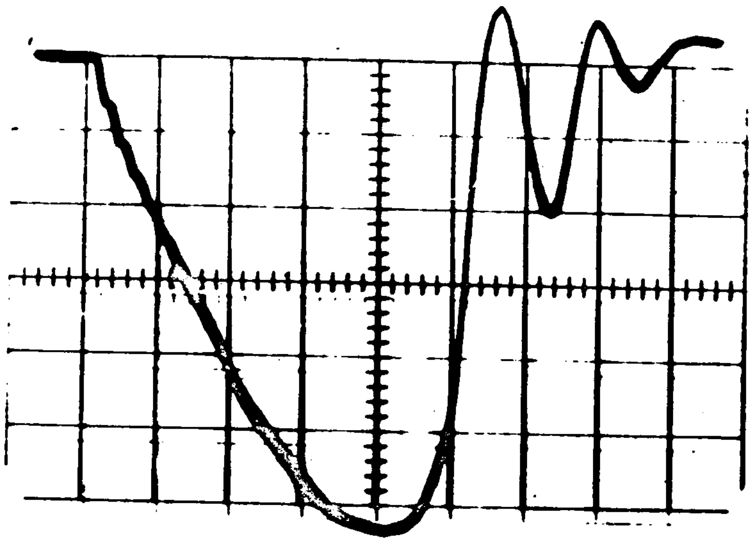

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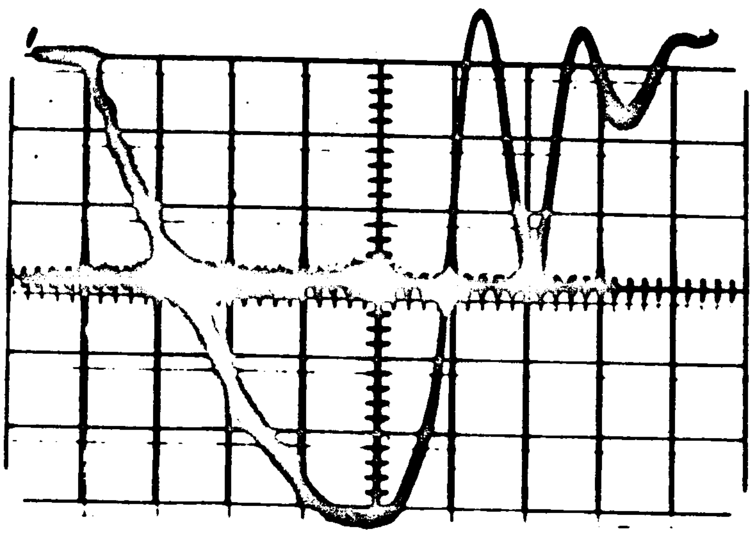

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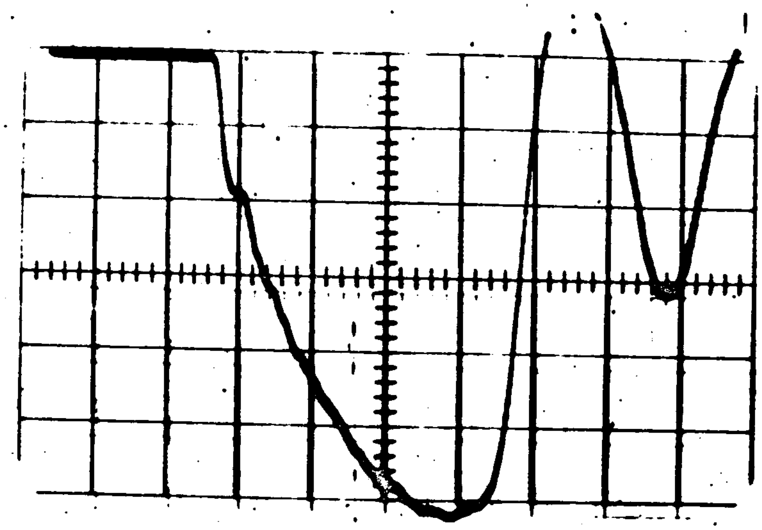

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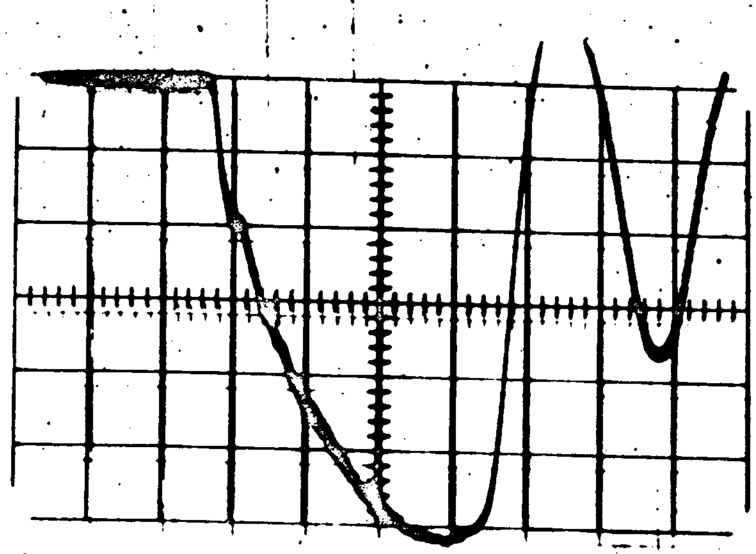

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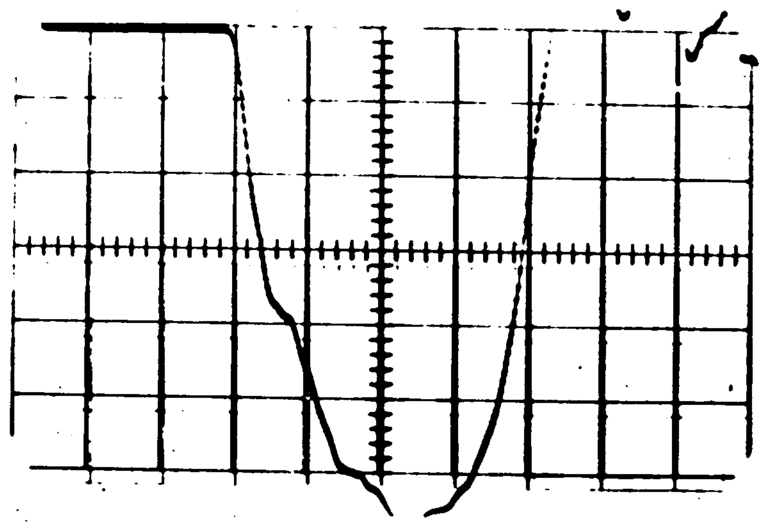

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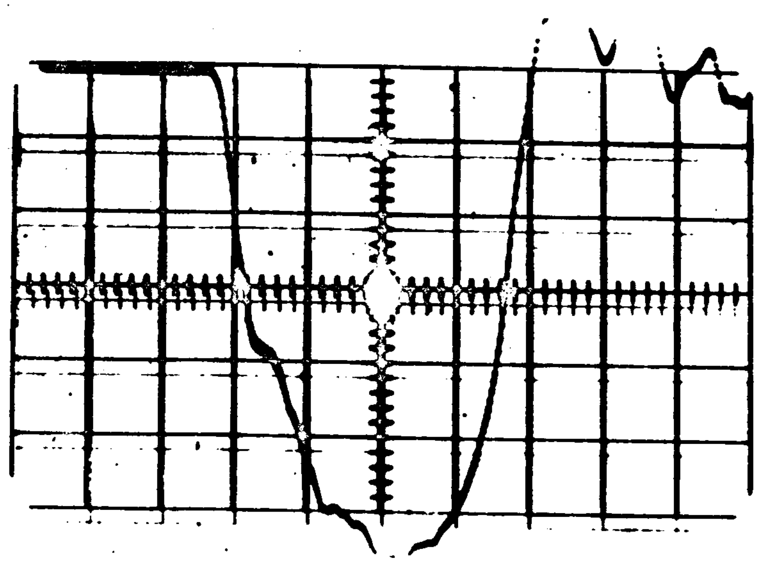

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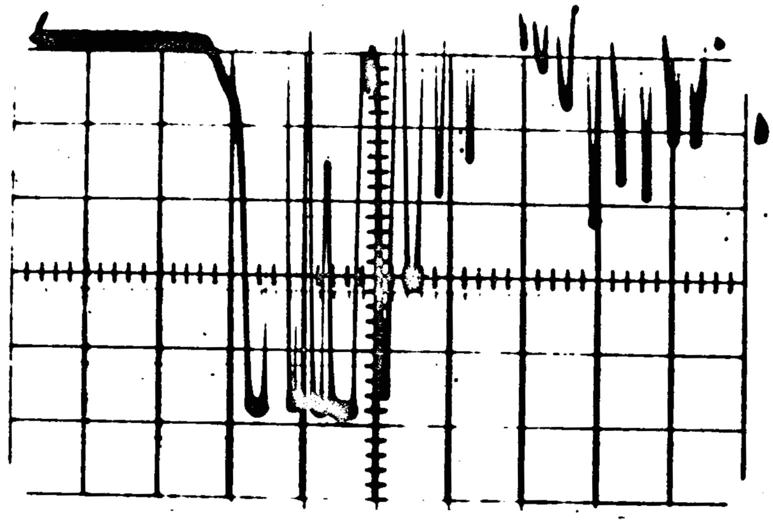

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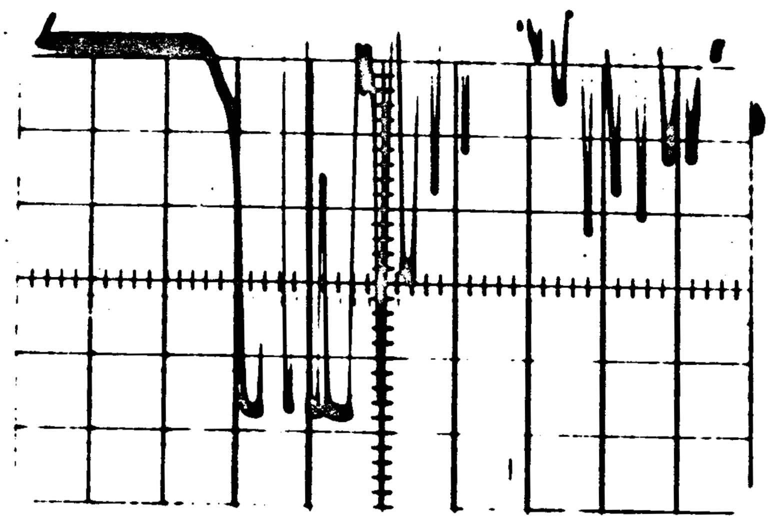

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Natural materials

The natural-material test that covers approximately the same range as the preceding tests are represented by Figures 17-34.

The scope internal voltage was again used on powdered pumice and quartz.

Note that on sand, like urethane foam, the spherical tip gives lower G values and greater pulse width than the conical tip, but that powdered pumice gives higher G values and the same or slightly lower pulse width. This also holds true in the vacuum tests.

The nature of the curves of lava and quartz reduces the accuracy with which they can be read.

It can be seen that the spread of numerical results is much greater for natural than man-made materials, but it is also evident that the shape of the curve offers a great deal of information that cannot be expressed in numbers.

Device No. ________ Vert. Sens. = .4714 RMS Cal. Voltage

Accel. Ser. No. DA58

Accel. E_s 34.0 peak mv/peak G

Circuit C_t 30.4 pf (measured)

Date 2/5 and 6/62

Observer W. L. Hall

System E_s = C_t x E_s x 2.4 x 10^{-3} mv/G

= 2.48 mv/G

Scope G Sens. = Vert. Sens. ÷ System E_s

Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Temp. °C	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
17 18	Pumice	3	Room		x	----	5.00	2.016	5.0	1.65 1.15	3.55 3.59	3.33 2.32	17.8 18.0		
19 20	Pumice	3	Room	x		----	5.00	2.016	5.0	3.24 3.15	3.05 3.56	6.53 6.35	15.3 17.8		
21 22	Sand	3	Room		x	15.00	7.071	2.851	5.0	4.40 4.32	2.53 2.26	12.5 12.3	12.7 11.3		
23 24	Sand	3	Room	x		15.00	7.071	2.851	5.0	2.78 3.00	3.18 3.56	7.93 8.55	15.9 17.8		
25 26	Lava	3	Room		x	119.9	56.52	22.79	1.0	3.5 4.1	3.20 2.62	80 93	3.2 2.6		
27 28	Lava	3	Room	x		258.0	121.6	49.04	.2	4.2 3.6	5.5 5.4	210 180	1.1 1.1		
29 30	Austin Chalk	3	Room		x	190.1	89.61	36.13	.2	6.18 6.25	3.71 3.61	223 226	.742 .722		
31 32	Marble	3	Room		x	538.5	253.8	102.4	.1	5.72 4.60	3.39 3.60	586 471	.339 .360		
33 34	Quartz	3	Room		x	----	1000	403.2	.05	5 4.5	3.5 3.4	2000 1800	.18 .17		

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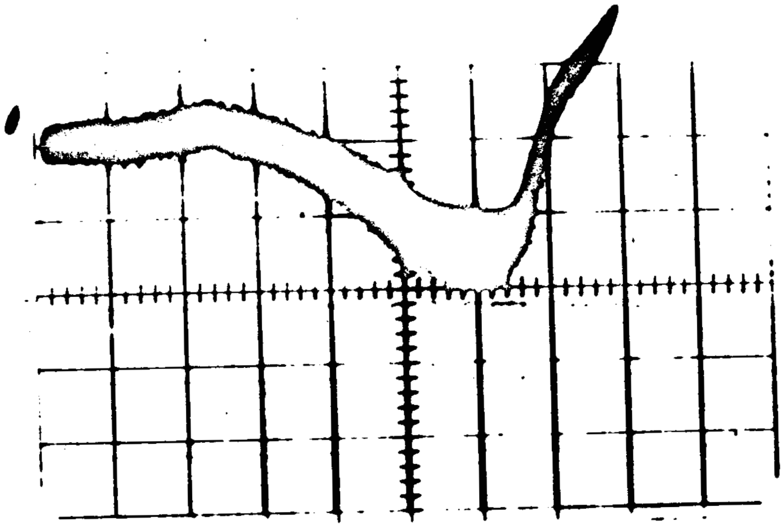

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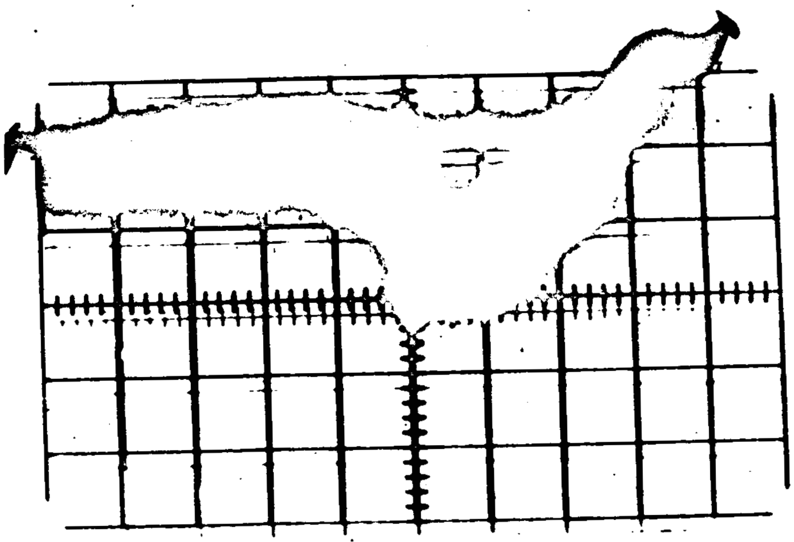

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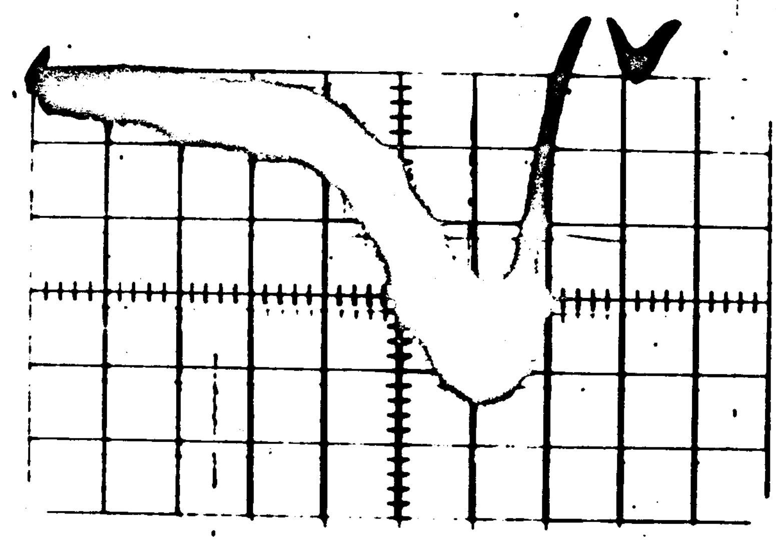

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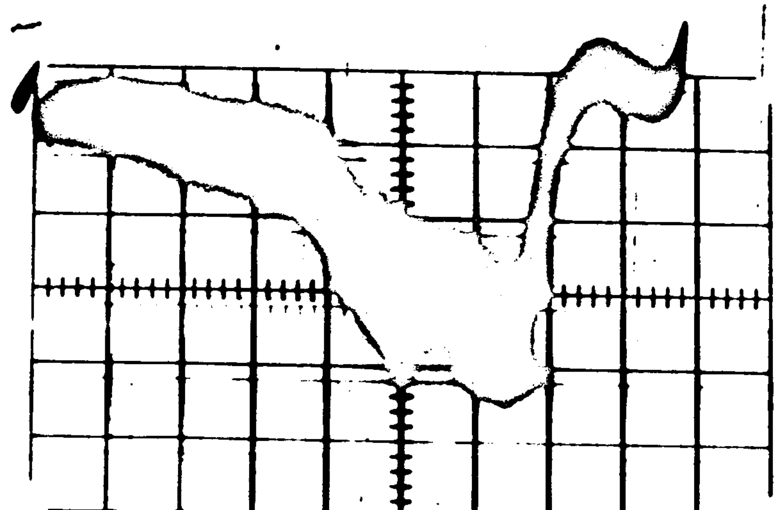

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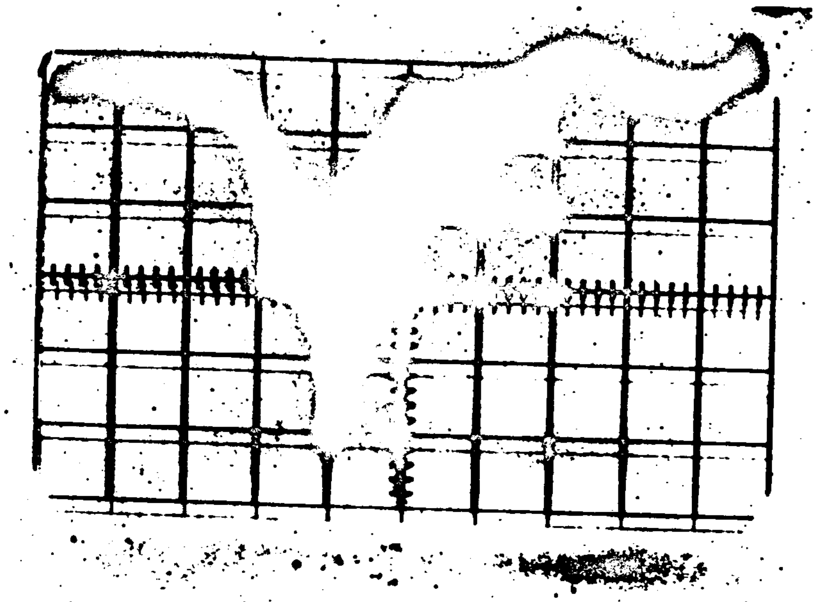

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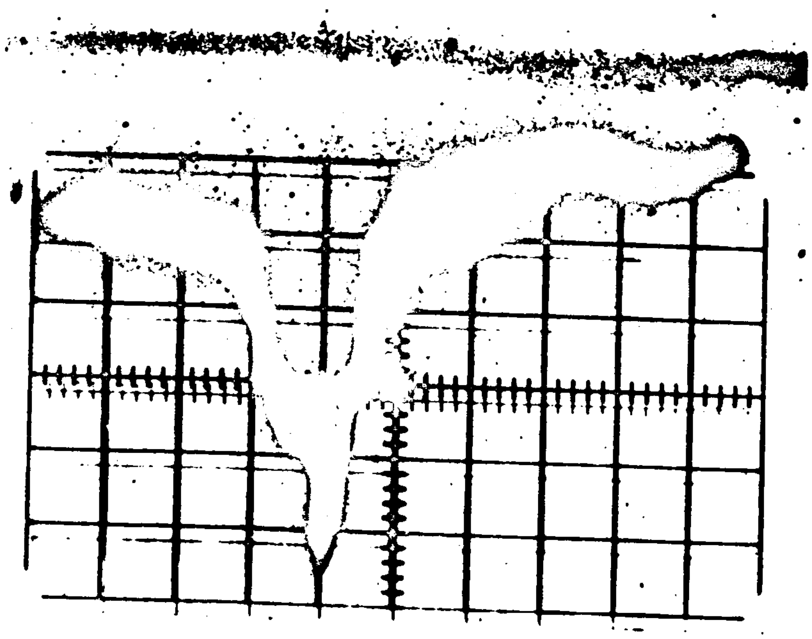
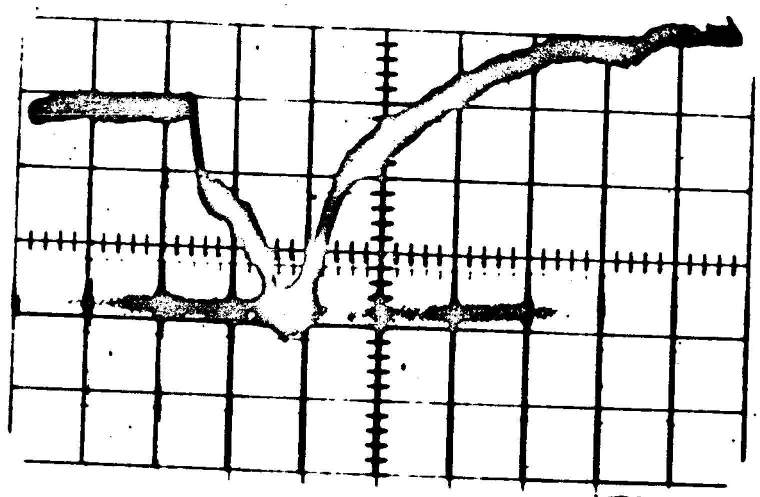


22

RE-ORDER No. 62-824

23



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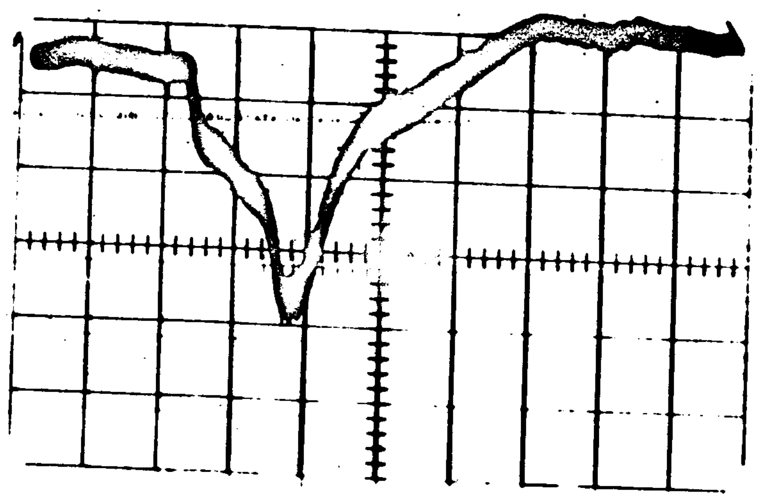

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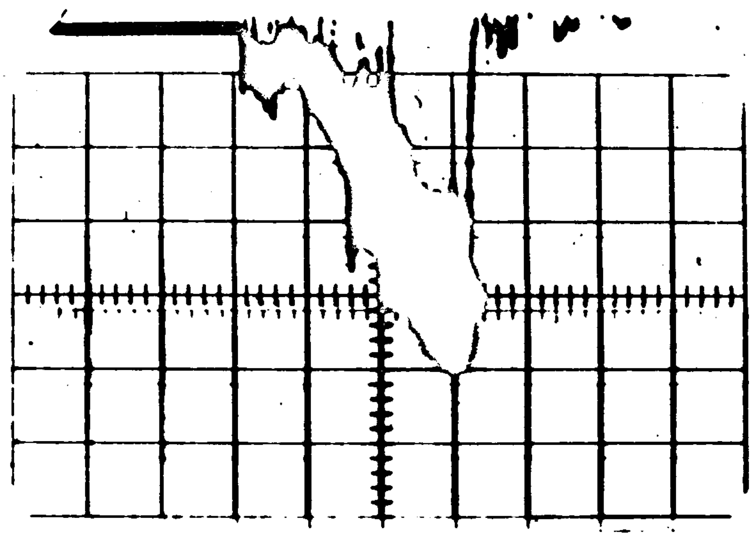

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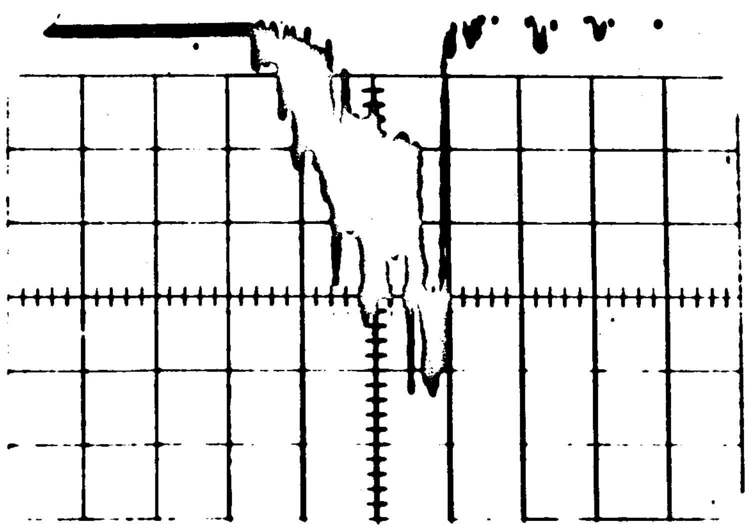

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RE-ORDER No. 62-824

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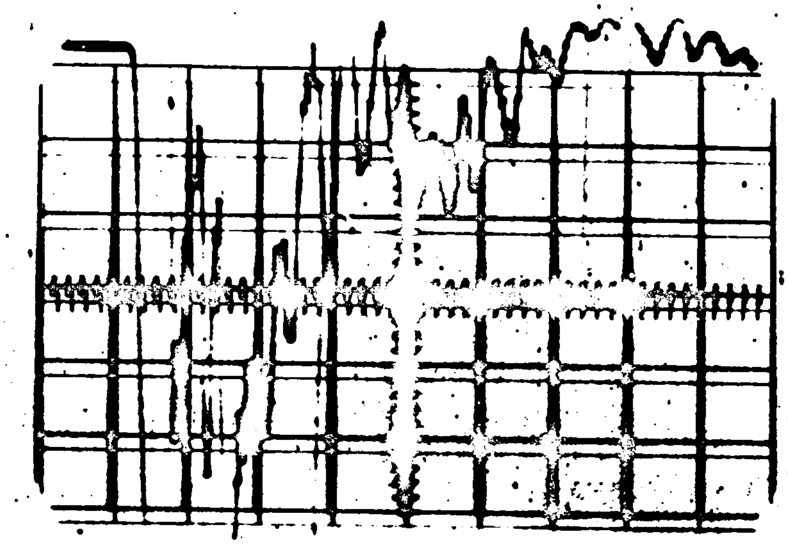

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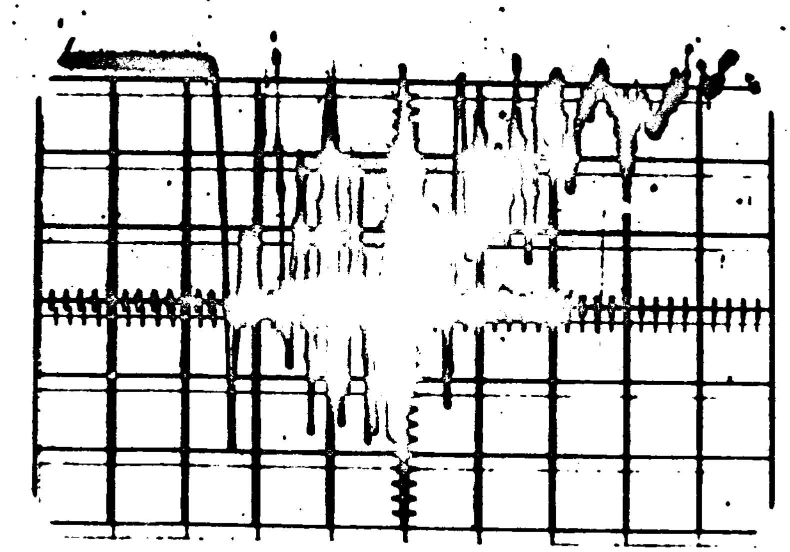

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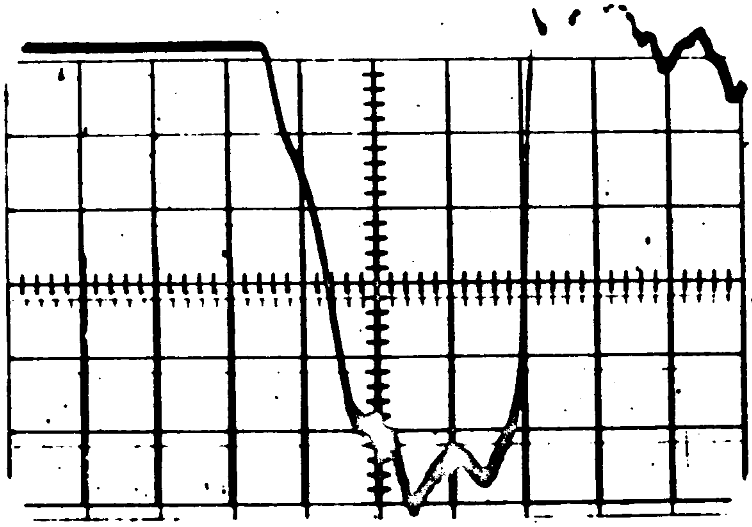

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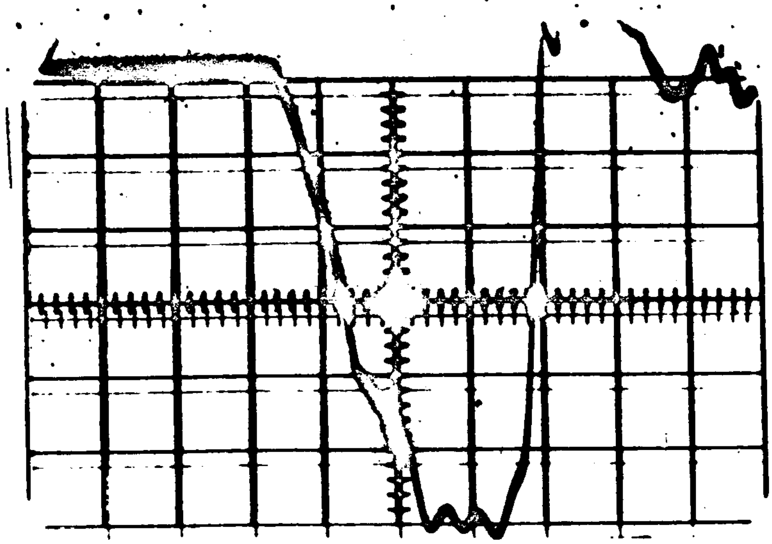

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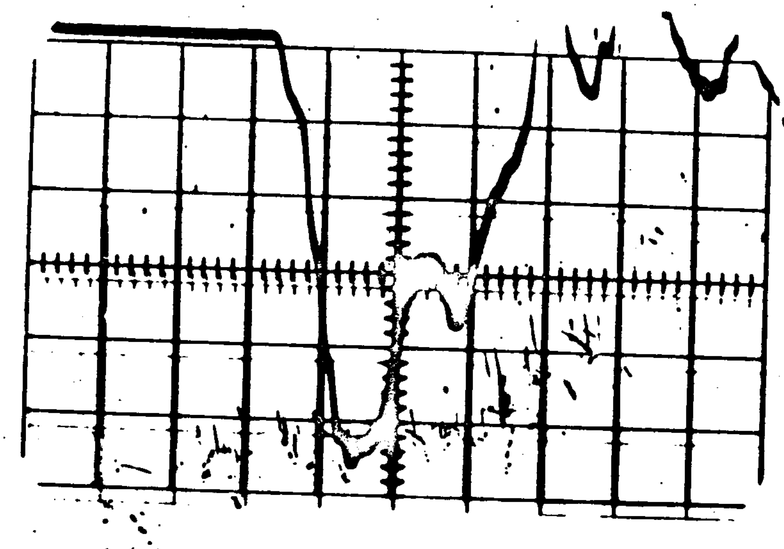

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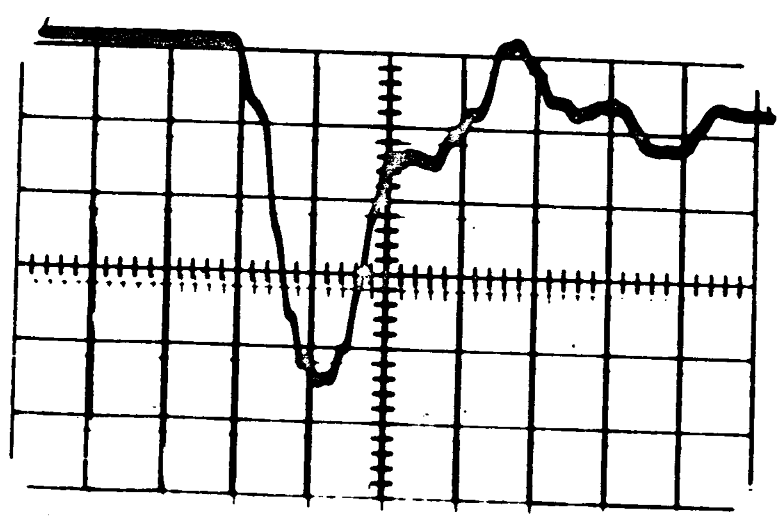

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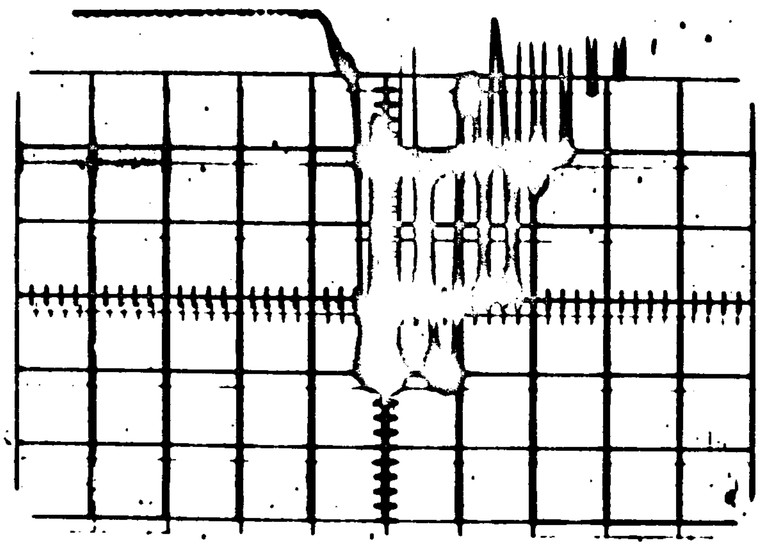

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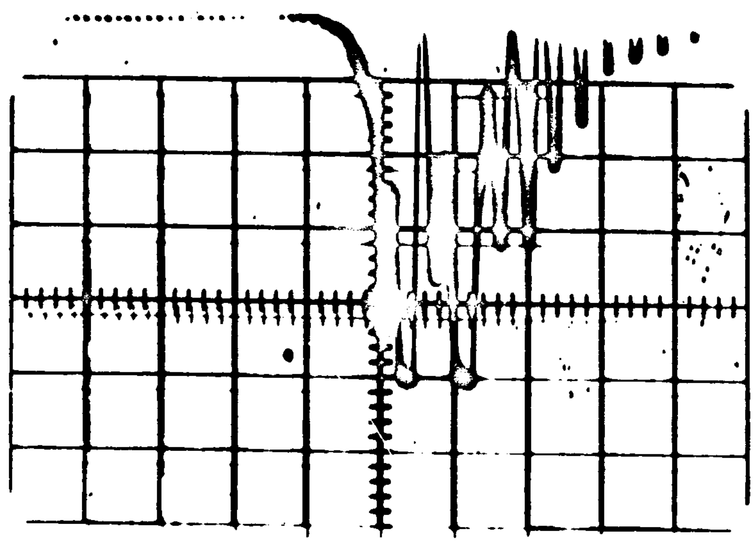


34

Variable drop height

The results of increasing drop heights are shown in Figures 35-54. The G values are plotted against drop height on Graphs 1 and 2.

The tendency appears to be an occasional abnormally high reading on sand, probably due to particle packing, with a change in slope at about 4 inches of drop height as the penetrometer begins to be completely submerged in the sand.

The change in slope of the curve on marble probably occurs as the tip begins to chip the marble.

The test fixture was adjusted for these tests to keep the same relationship between pivot and undropped penetrometer for all drop heights. This simulates the effect of the spacecraft foot sinking to different depths.

Device No. ________ Vert. Sens. = .4714 RMS Cal. Voltage System E_s = C_t x E_s x 2.4 x 10^{-3} mv/G

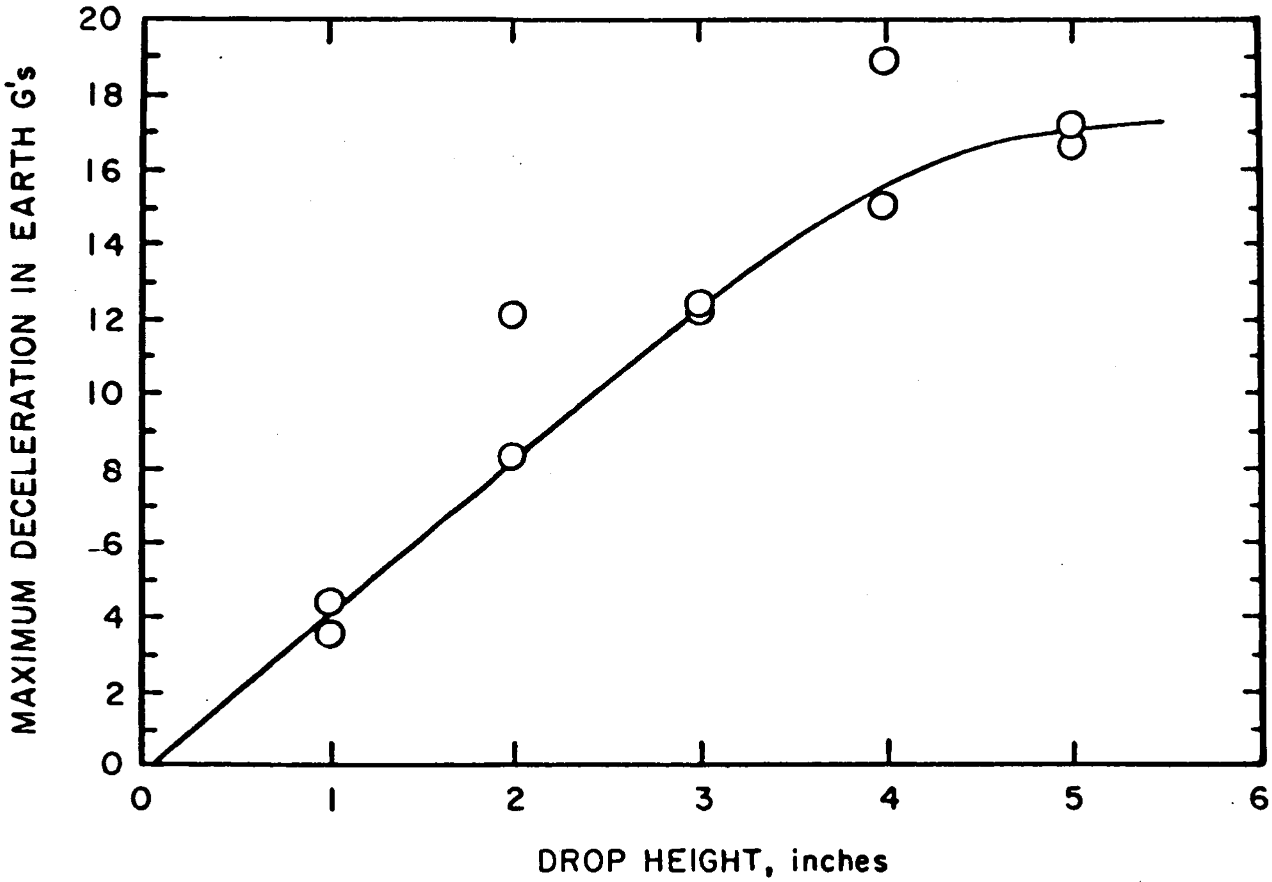
Accel. Ser. No. DA58 = 2.48 mv/G

Accel. E_s 34.0 peak mv/peak G Date 2/6/62 Scope G Sens. = Vert. Sens. ÷ System E_s

Circuit C_t 30.4 pf (measured) Observer W. L. Hall Note: G units refer to earth G's

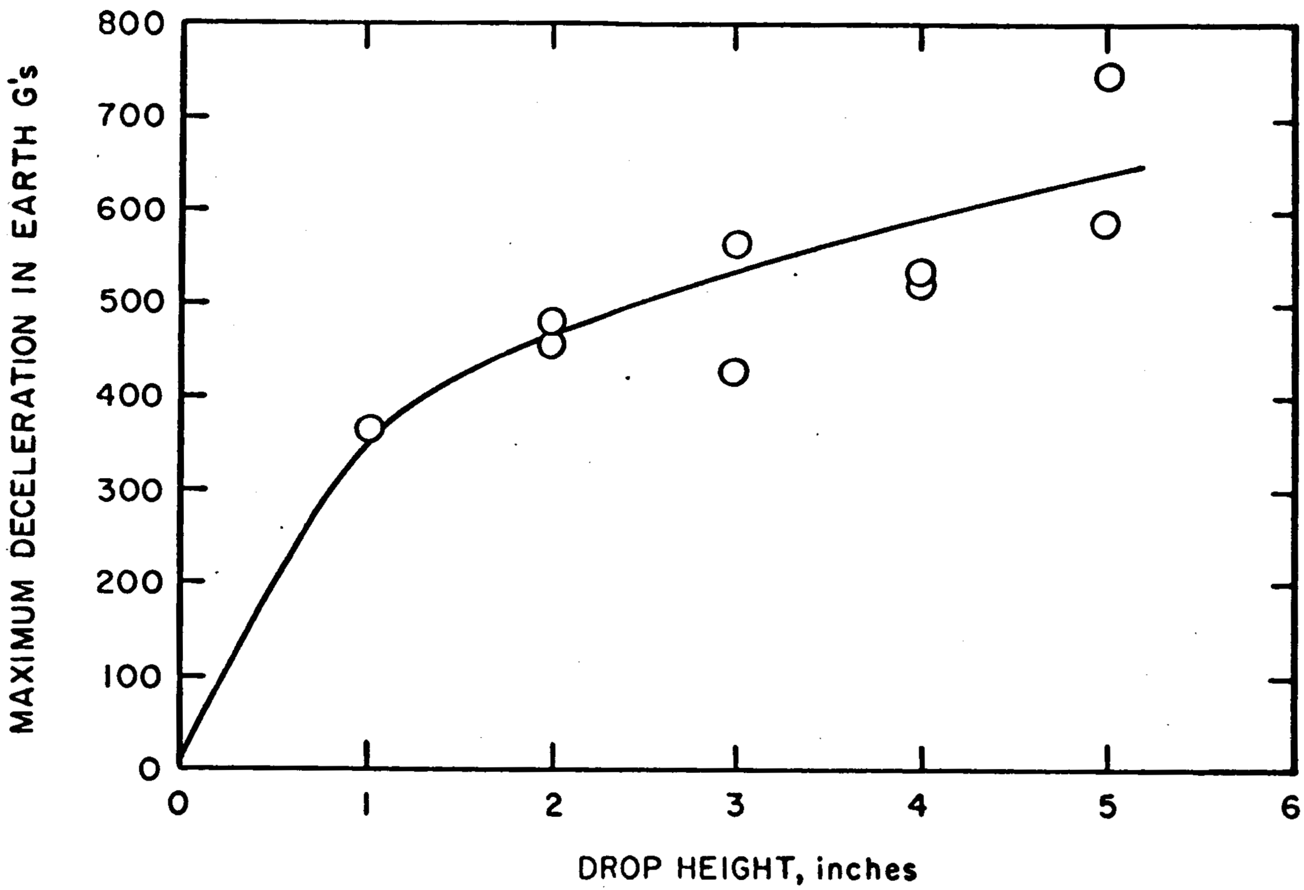
Fig. No.	Material	Drop Ht. Inches	Temp. °C	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
35 36	Sand	1	Room		x	15.00	7.071	2.851	5.0	1.53 1.27	3.08 4.38	4.36 3.62	15.4 21.9		
37 38	Sand	2	Room		x	15.00	7.071	2.851	5.0	2.90 4.23	2.22 2.98	8.27 12.1	11.1 14.9		
39 40	Sand	3	Room		x	15.00	7.071	2.851	5.0	4.40 4.32	2.53 2.26	12.5 12.3	12.7 11.3		
41 42	Sand	4	Room		x	-----	10.00	4.032	5.0	4.69 3.71	1.79 2.20	18.9 15.0	9.0 11.0		
43 44	Sand	5	Room		x	-----	10,00	4.032	5.0	4.24 4.14	2.10 2.12	17.1 16.7	10.5 10.6		
45 46	Marble	1	Room		x	277.6	130.9	52.77	.1	6.85 6.85	3.10 3.18	361 361	.310 .318		
47 48	Marble	2	Room		x	418.9	197.5	79.62	.1	5.72 6.02	3.44 3.31	455 479	.344 .331		
49 50	Marble	3	Room		x	538.5	253.8	102.4	.1	4.15 5.50	3.81 3.60	425 563	.381 .360		
51 52	Marble	4	Room		x	617.8	291.2	117.4	.1	4.55 4.44	4.01 3.63	534 521	.401 .363		
53 54	Marble	5	Room		x	617.8	291.2	117.4	.1	6.35 4.15	5.69 5.88	745 485	.569 .588		

RE-ORDER No. 62-824

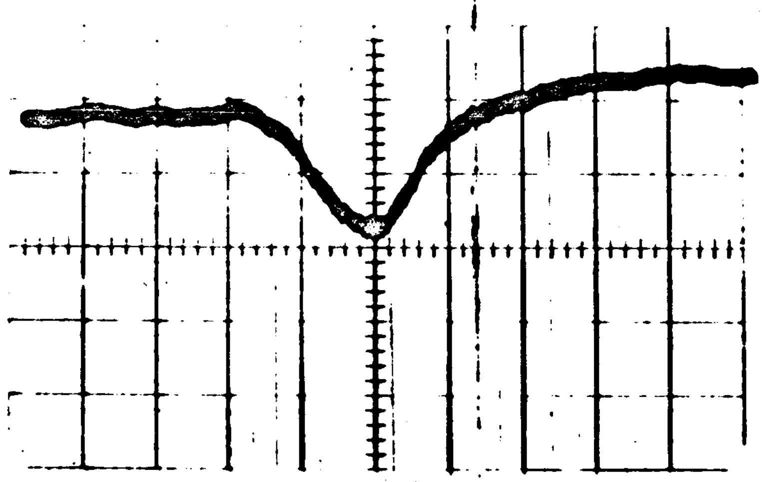


GRAPH I. PENETROMETER VARIABLE DROP HEIGHT TESTS IN SAND

RE-ORDER No. 62-824



GRAPH 2. PENETROMETER VARIABLE DROP HEIGHT TESTS ON MARBLE



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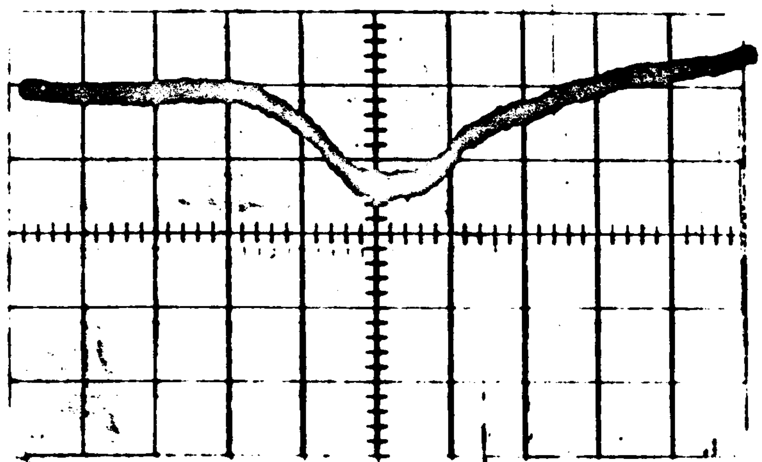

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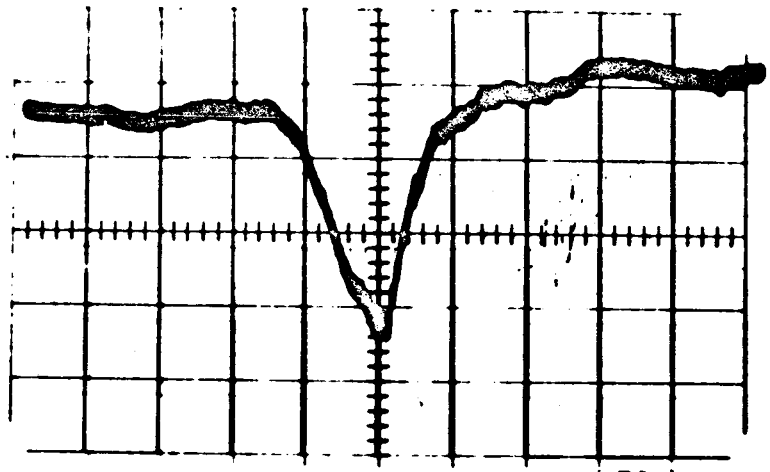

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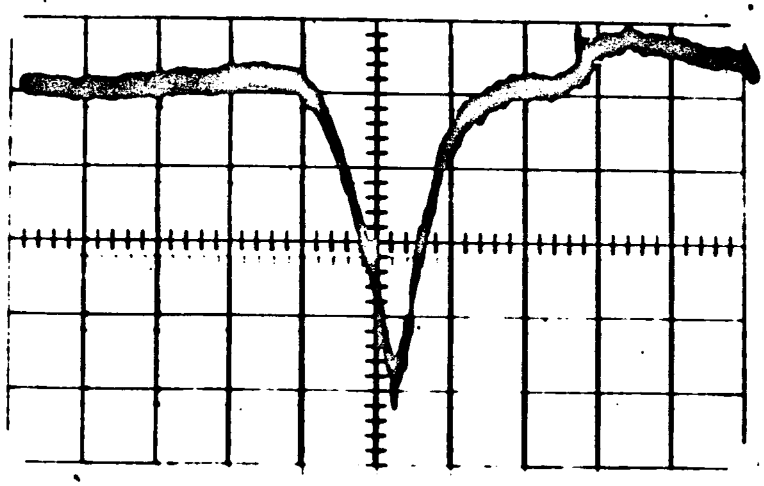

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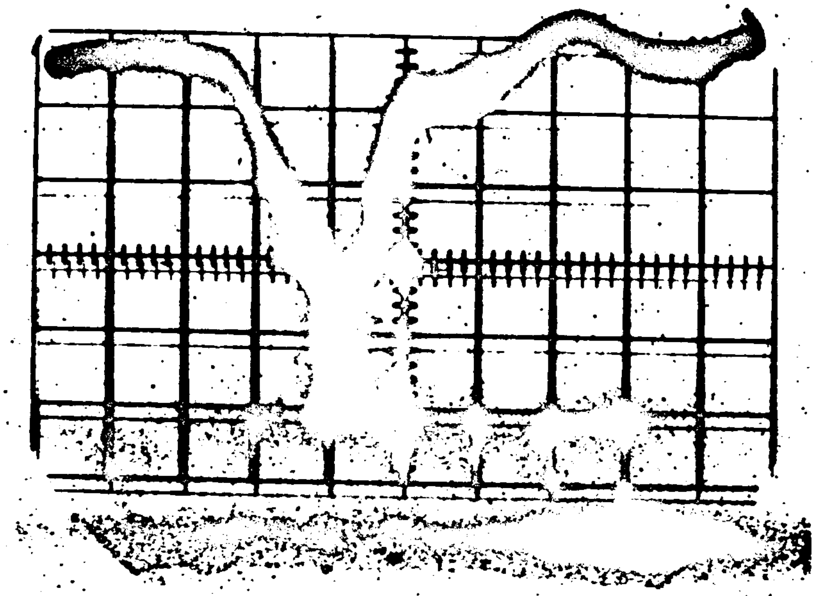

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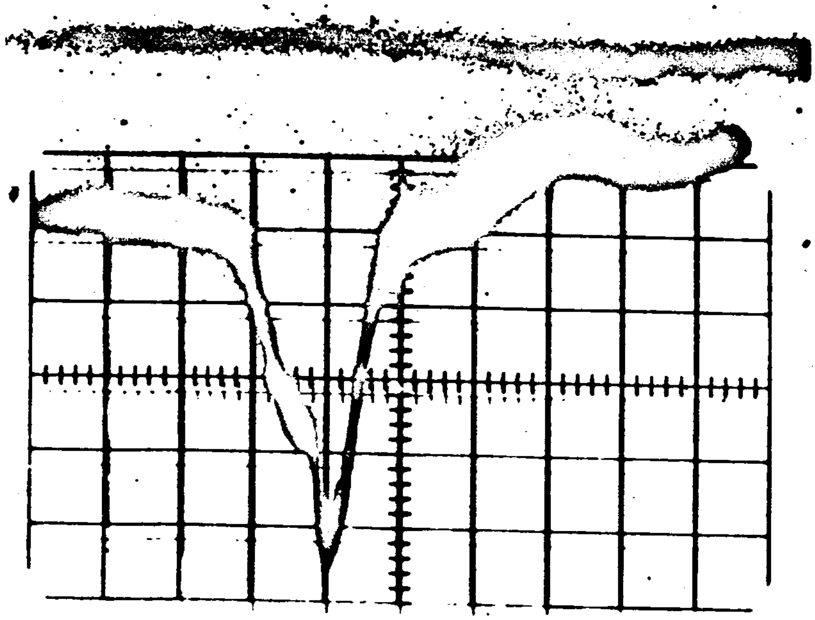

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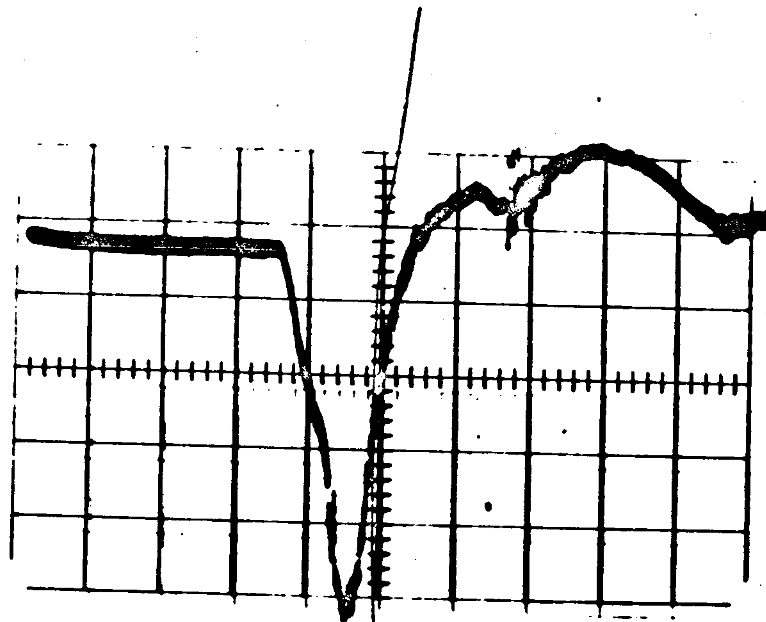

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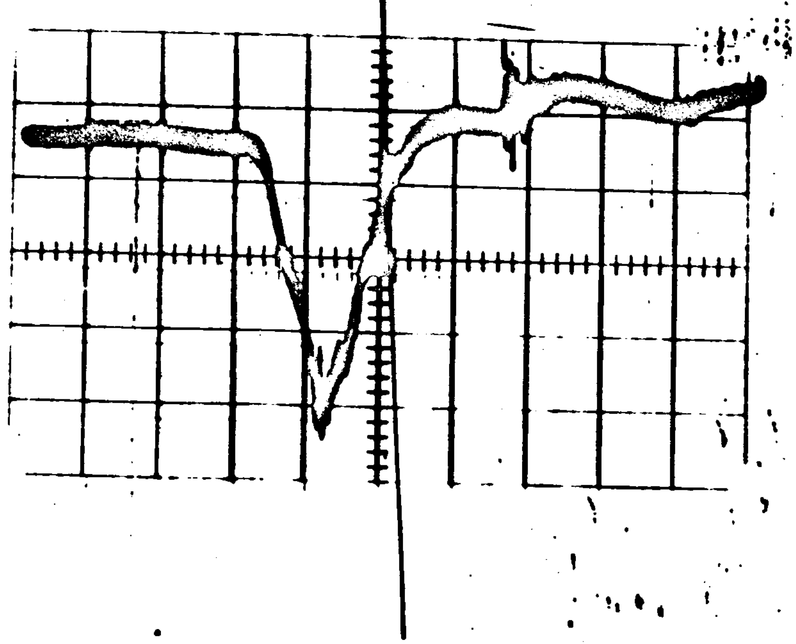

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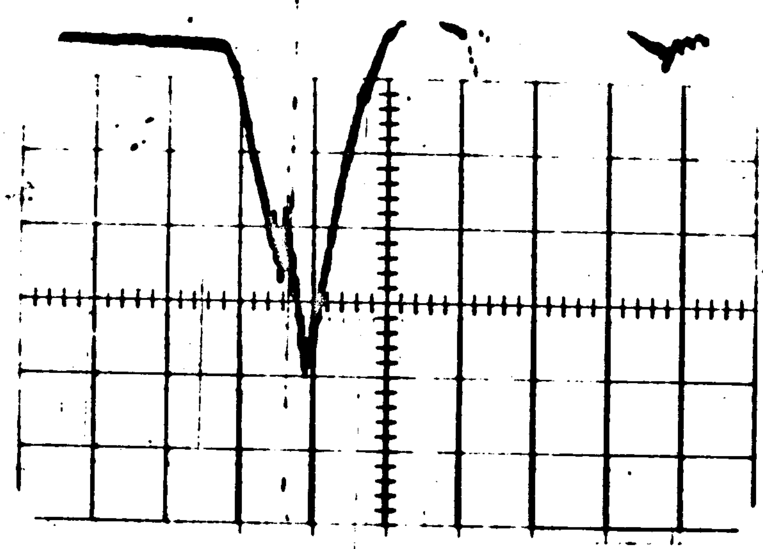
RE-ORDER No. 62-824 43



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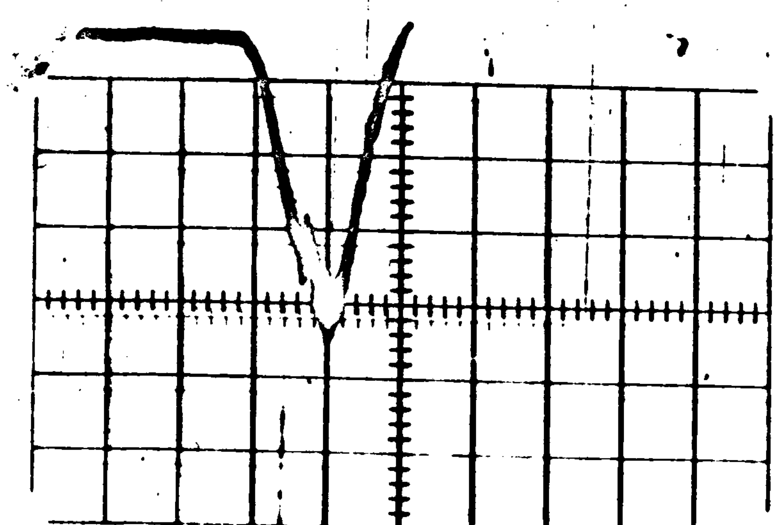

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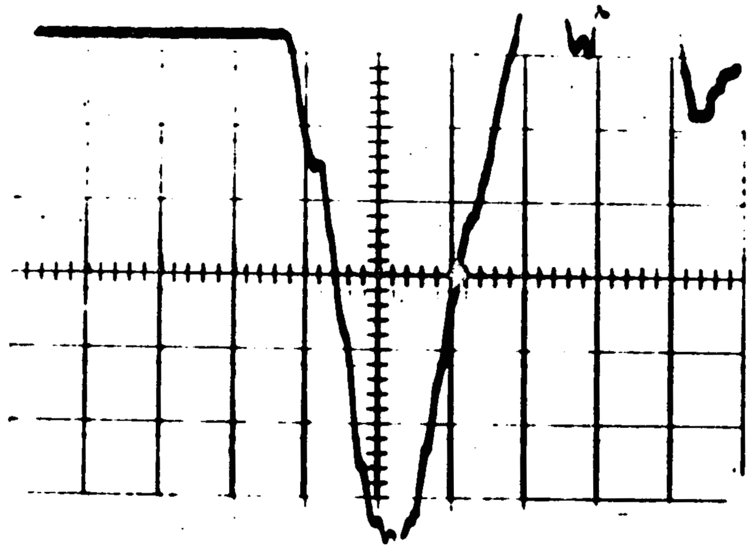

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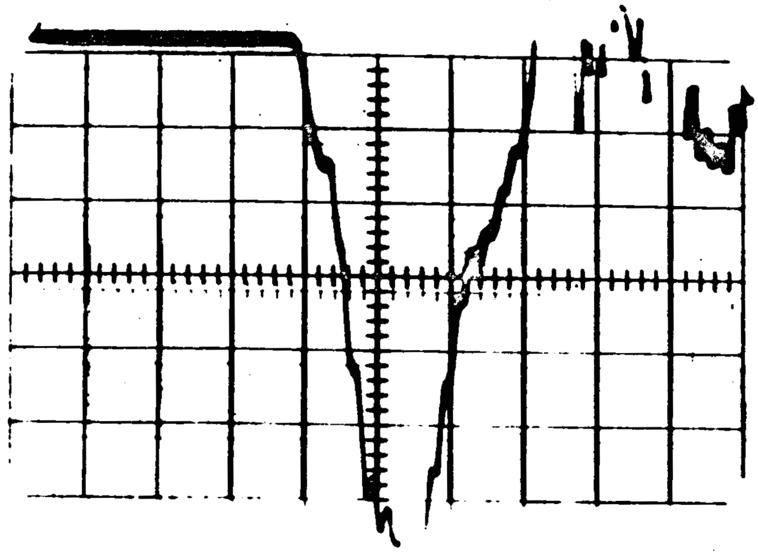

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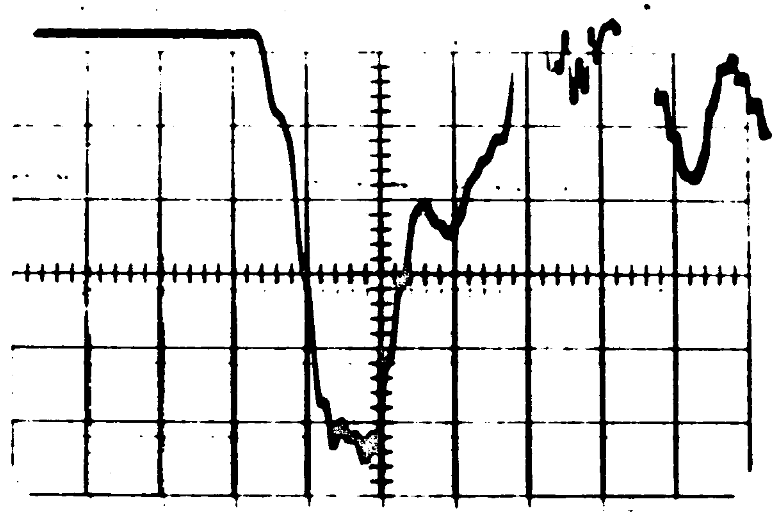

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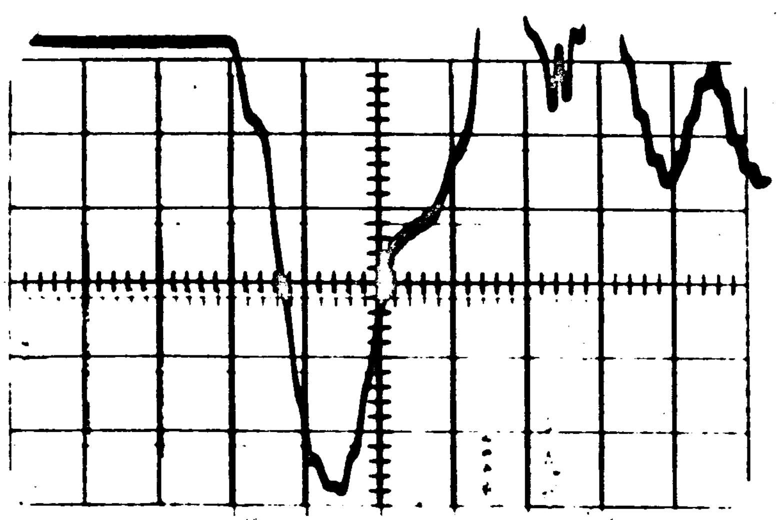

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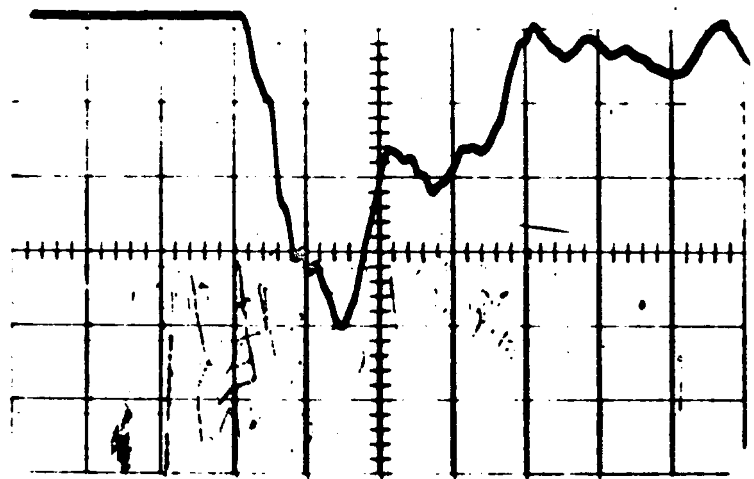

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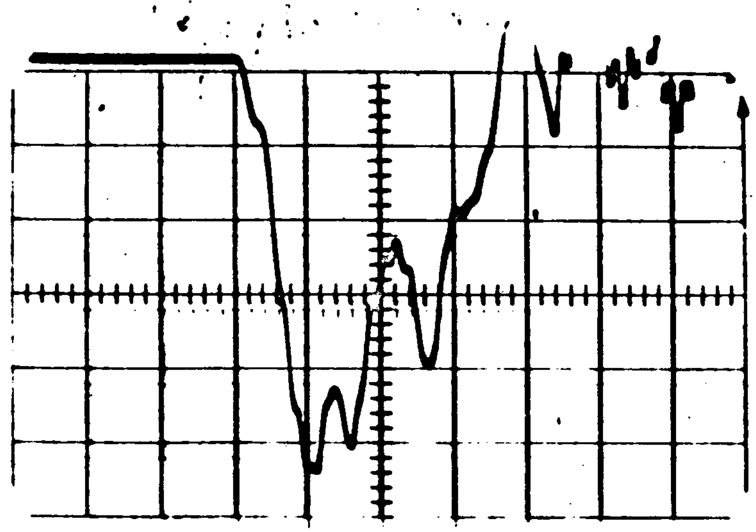

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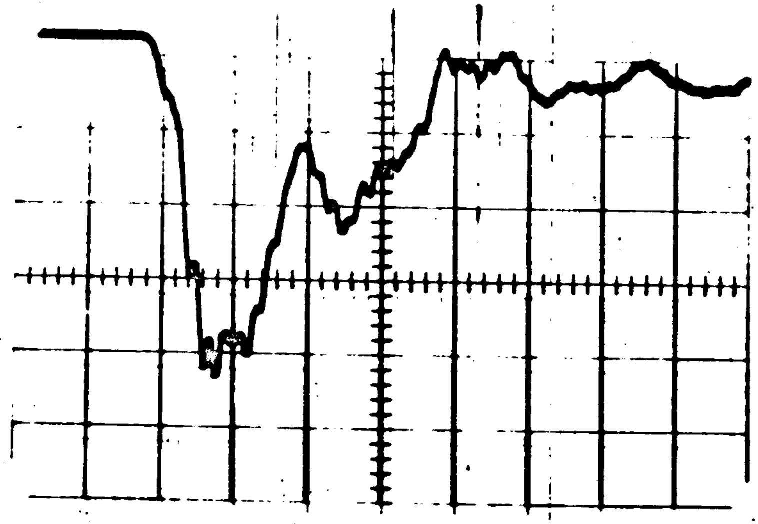

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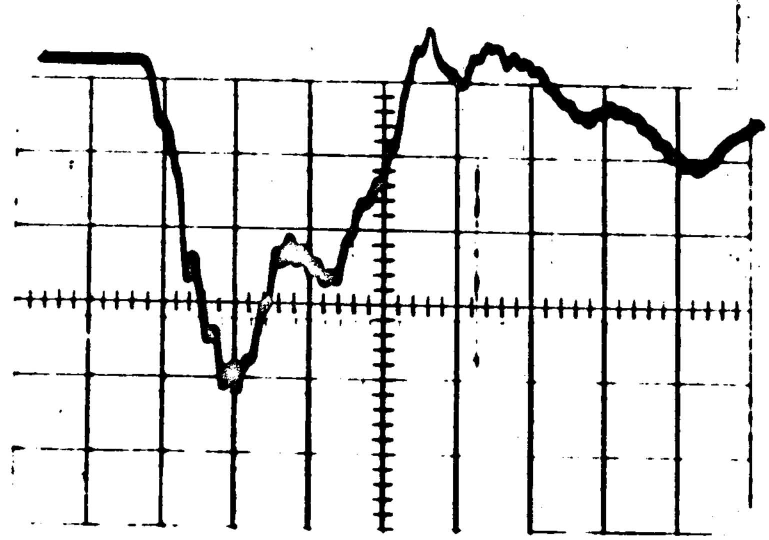

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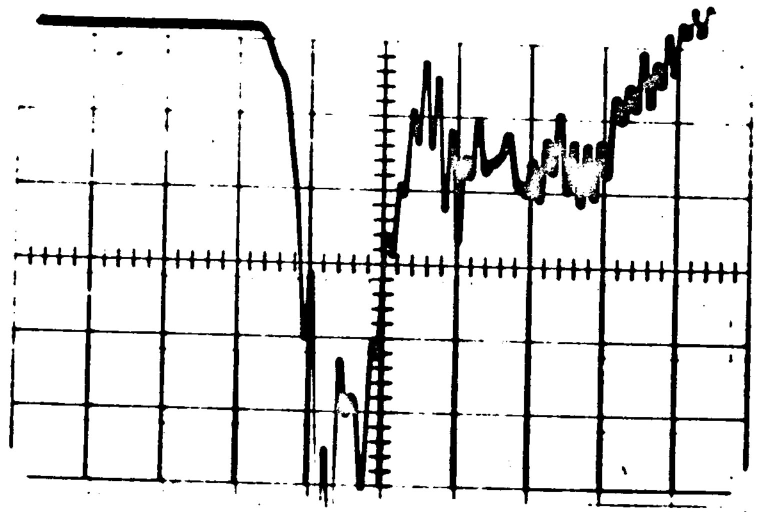

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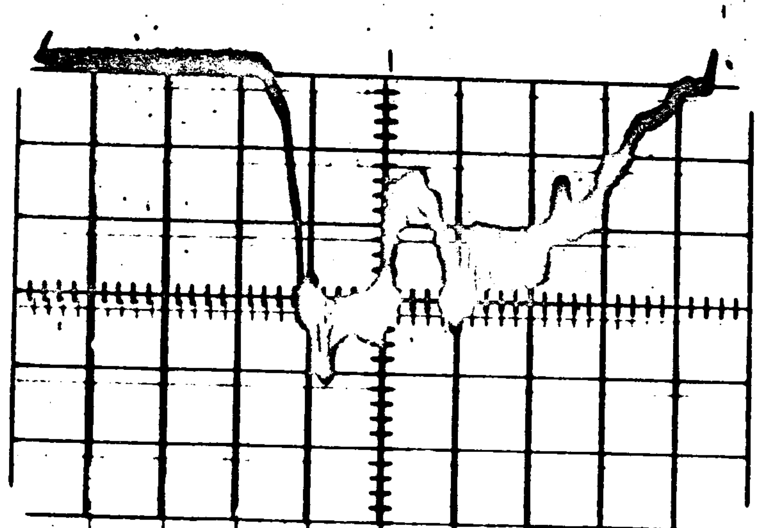

54

Vacuum chamber

Figures 55-78 show the vacuum-chamber tests. The test fixture was set up in the chamber, and tests were made in the chamber at atmospheric pressure for comparison to those made at 1 micron.

The atmospheric values do not agree with the bench tests because different containers and test samples were used. The comparison, however, should be valid.

Note that the resistance to penetration in a vacuum decreases markedly in the case of pumice, but increases in the cases of sand and lava.

Device No. ________ Vert. Sens. = .4714 RMS Cal. Voltage System K_s = $C_t \times K_s \times 2.4 \times 10^{-3}$ mv/G

Accel. Ser. No. DA58 = 2.48 mv/G

Accel. K_s 34.0 peak mv/peak G Date 2/8/62 Scope G Sens. = Vert. Sens. ÷ System K_s

Circuit C_t 30.4 pf (measured) Observer W. L. Hall Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Pressure mm Hg	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
55 56	Pumice	3	Atm		x	-----	5.00	2.016	5.0	3.30 3.91	2.50 3.07	6.65 7.88	12.5 15.4		
57 58	Pumice	3	10^{-3}		x	-----	5.00	2.016	5.0	2.08 1.96	3.50 2.54	4.19 3.95	17.5 12.7		
59 60	Pumice	3	Atm	x		-----	5.00	2.016	5.0	4.71 4.40	2.50 2.00	9.50 8.87	12.5 10.0		
61 62	Pumice	3	10^{-3}	x		-----	5.00	2.016	5.0	1.80 1.72	3.60 4.56	3.63 3.47	18.0 22.8		
63 64	Sand	3	Atm		x	15.00	7.071	2.851	5.0	3.06 2.76	2.43 2.19	8.72 7.87	12.2 11.0	---	
65 66	Sand	3	10^{-3}		x	15.00	7.071	2.851	5.0	4.83 5.12	1.33 1.30	13.8 14.6	6.7 6.5		
67 68	Sand	3	Atm	x		15.00	7.071	2.851	5.0	2.13 2.59	3.33 3.14	6.07 7.38	16.7 15.7		
69 70	Sand	3	10^{-3}	x		15.00	7.071	2.851	5.0	3.94 5.65	..87 .78	11.2 16.1	4.4 3.9		
71 72	Lava	3	Atm		x	119.9	56.52	22.79	1.0	3.6 2.4	3.5 3.3	82 55	3.5 2.4		
73 74	Lava	3	10^{-3}		x	119.9	56.52	22.79	1.0	3.1 3.2	3.6 3.2	71 73	3.6 3.2		
75 76	Lava	3	Atm	x		258.0	121.6	49.04	.2	2.6 2.6	6.8 7.2	130 130	1.4 1.4		

44

RE-ORDER No. 62-824

Device No. ________

Accel. Ser. No. DA58

Accel. E_s 34.0 peak mv/peak G

Circuit C_t 30.4 pf (measured)

Vert. Sens. = .4714 RMS Cal. Voltage

Date 2/8/62

Observer W. L. Hall

System E_s = C_t x E_s x 2.4 x 10^{-3} mv/G

= 2.48 mv/G

Scope G Sens. = Vert. Sens. ÷ System E_s

Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Pressure mm Hg	Tip		Oscilloscope				Measured		Calculated		Standard	
				Sphere	Cone	RMS Cal. Voltage mv/6cm	Vert. Sens. mv/cm	G Sens. G's/cm	Sweep msec/cm	Pulse Height cm	Pulse Width cm	Pulse Height G's	Pulse Width msec	Pulse Height G's	Pulse Width msec
77 78	Lava	3	10^{-3}	x		258.0	121.6	49.04	.2	3.4 3.4	8.5 7.4	170 170	1.7 1.5		

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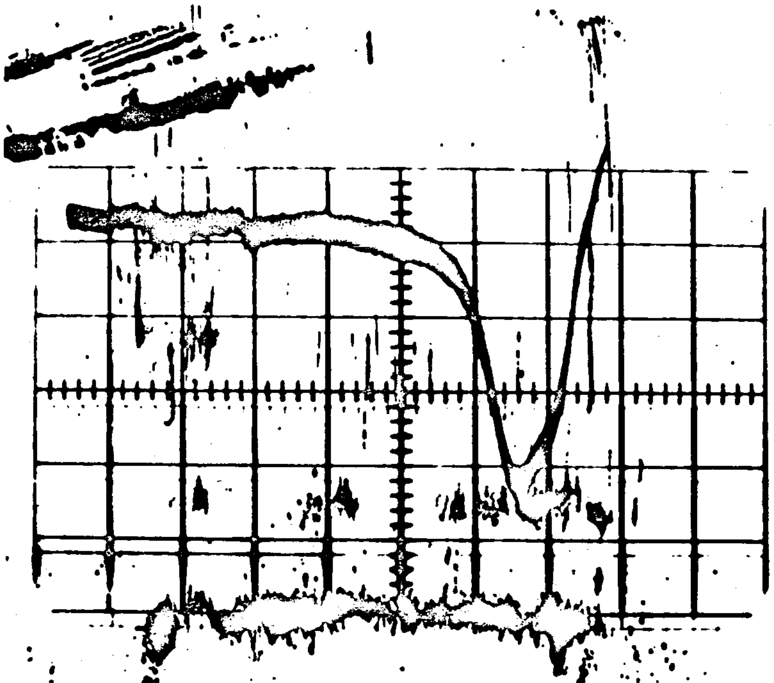
RE-ORDER No. 62-824



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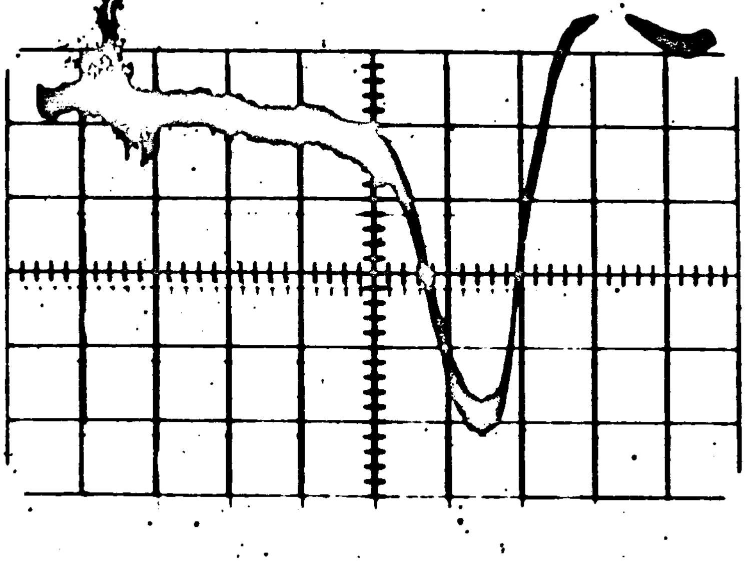

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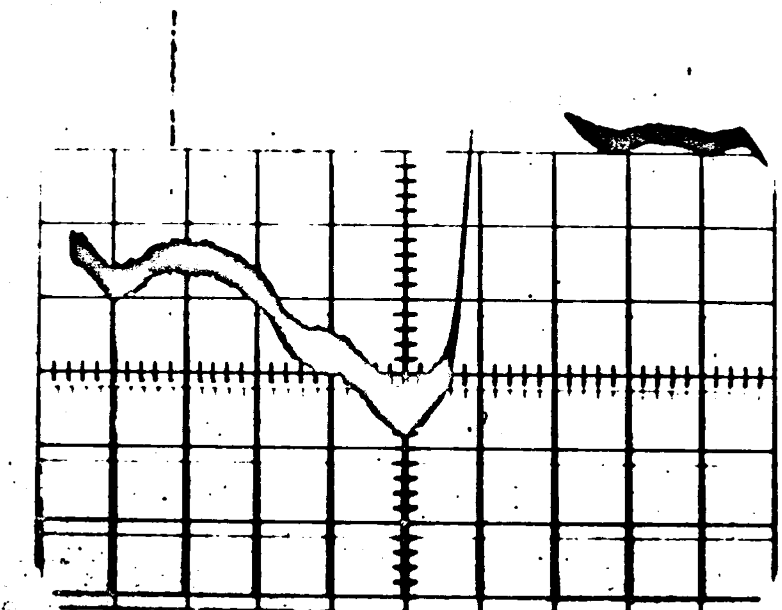

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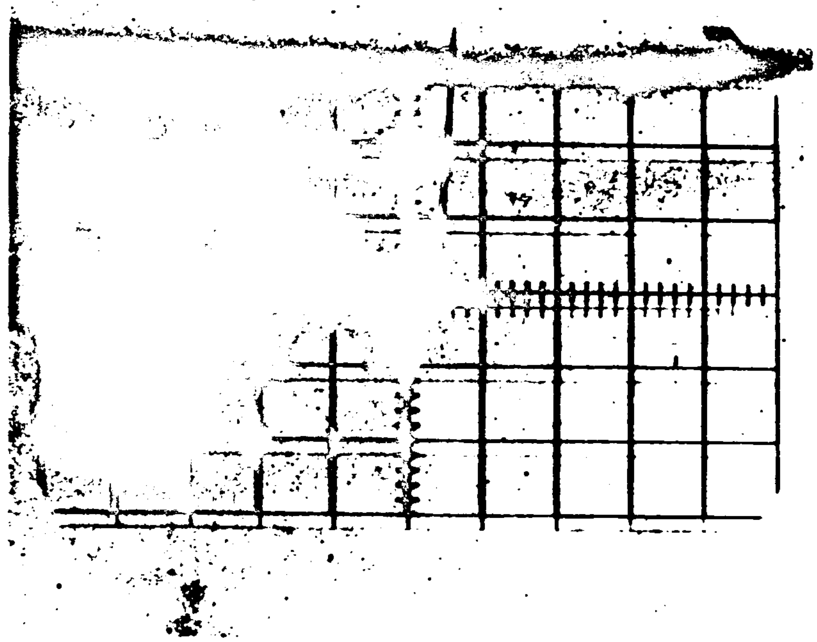

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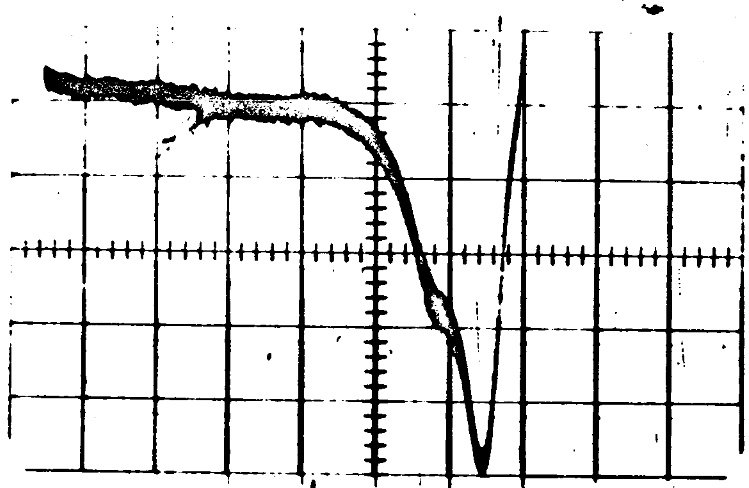

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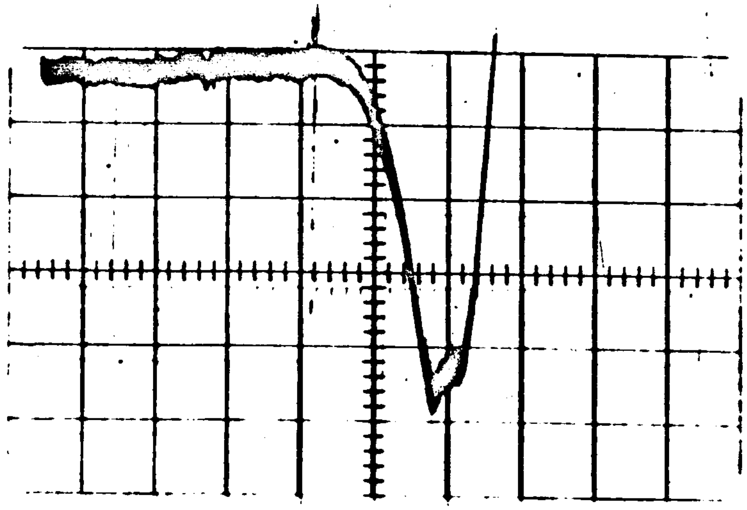

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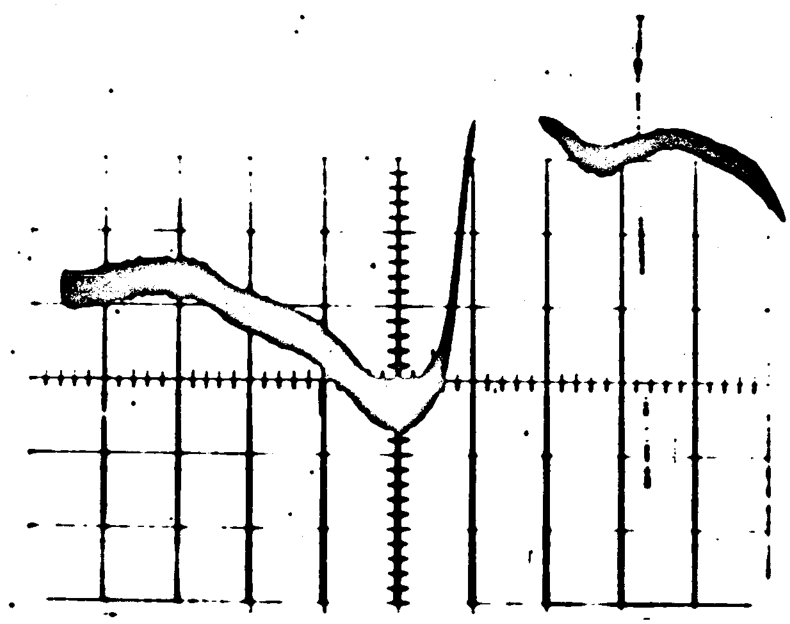

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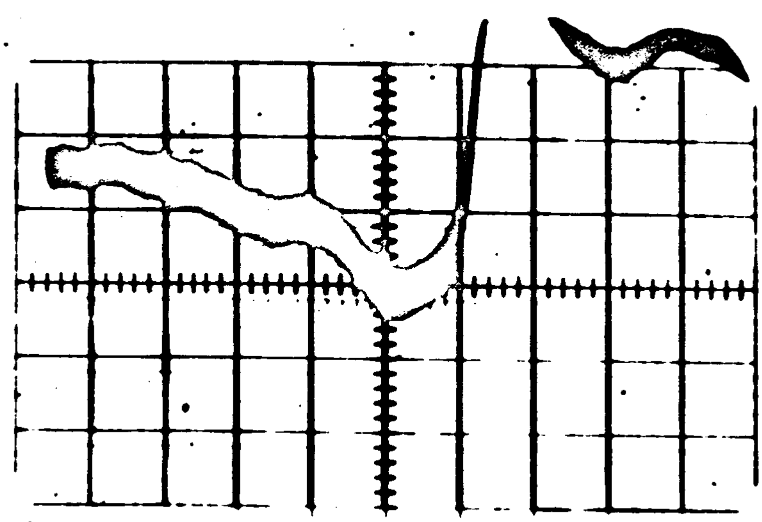

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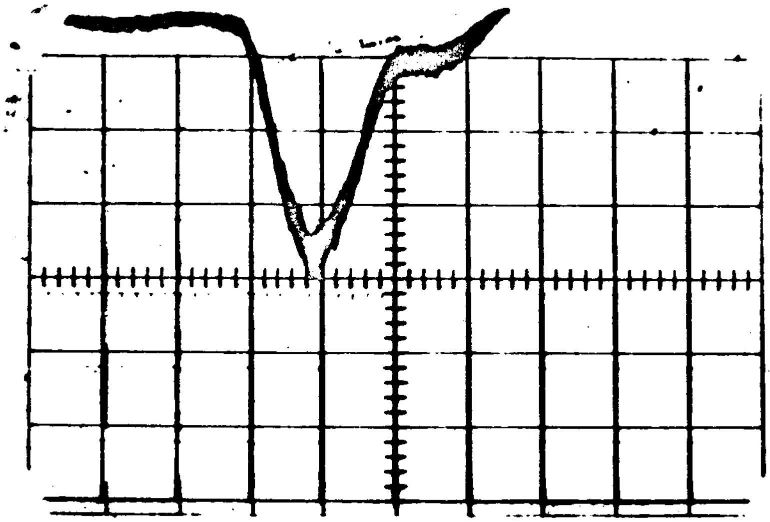

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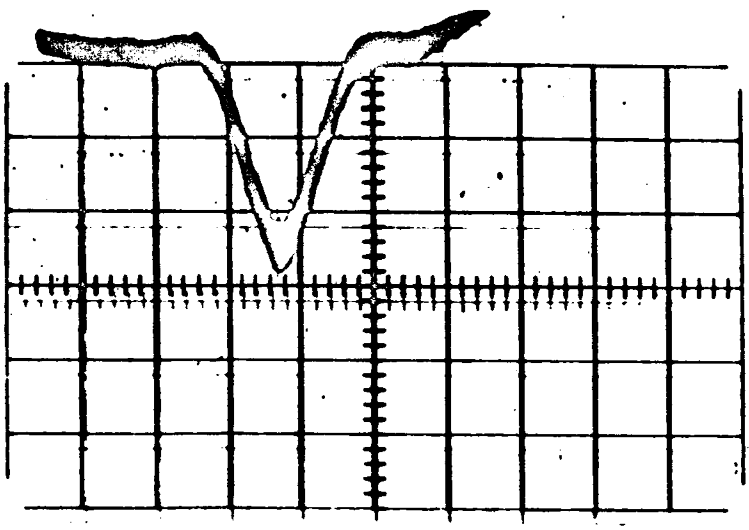

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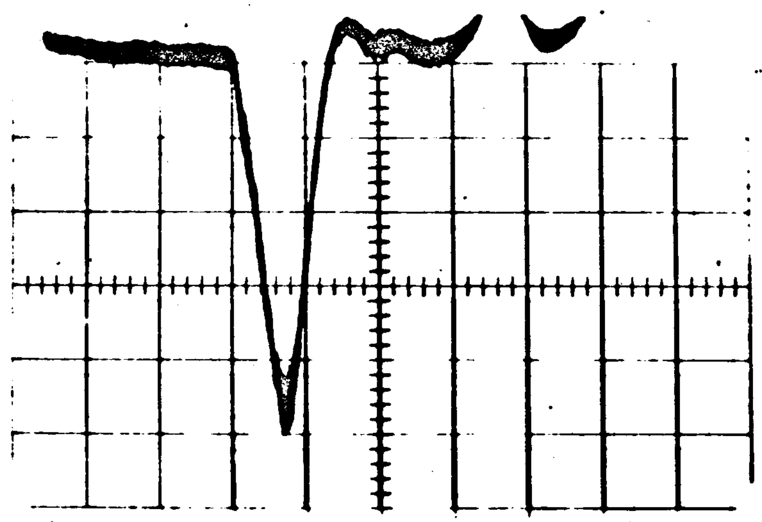

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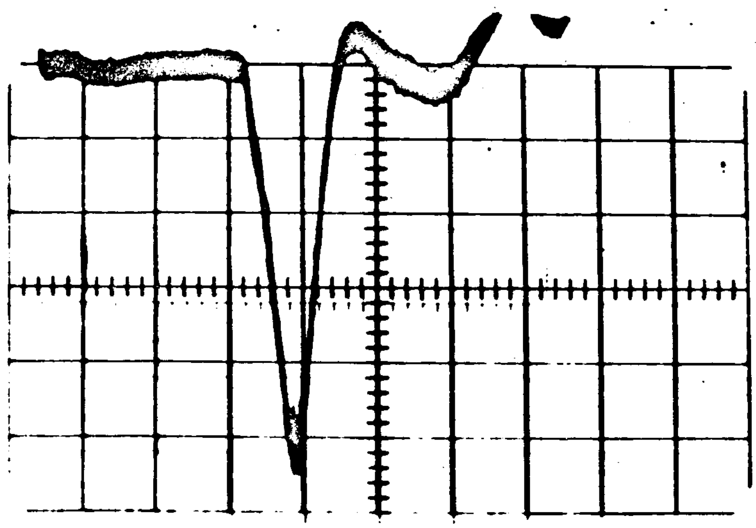

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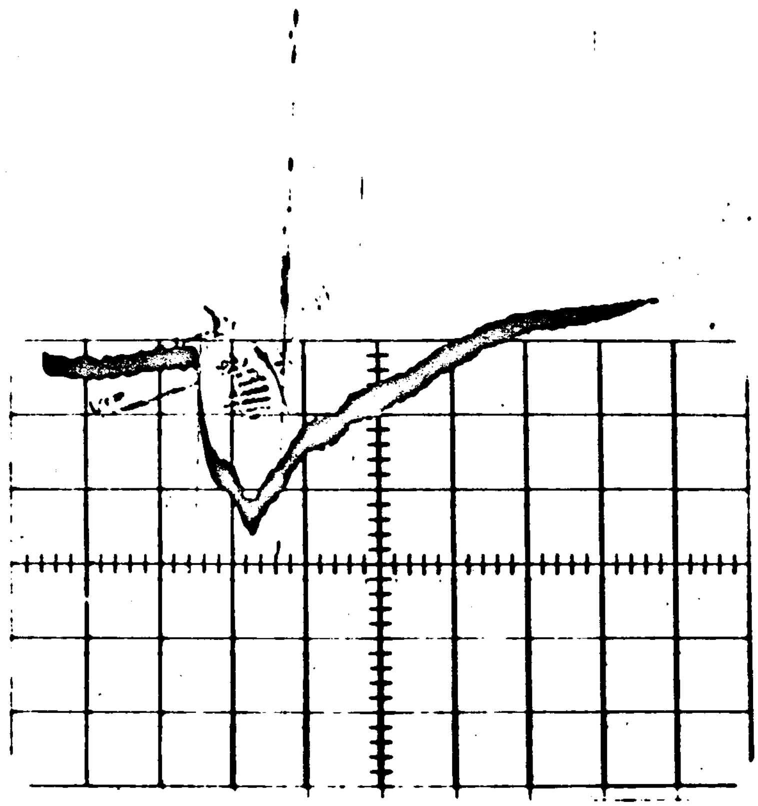

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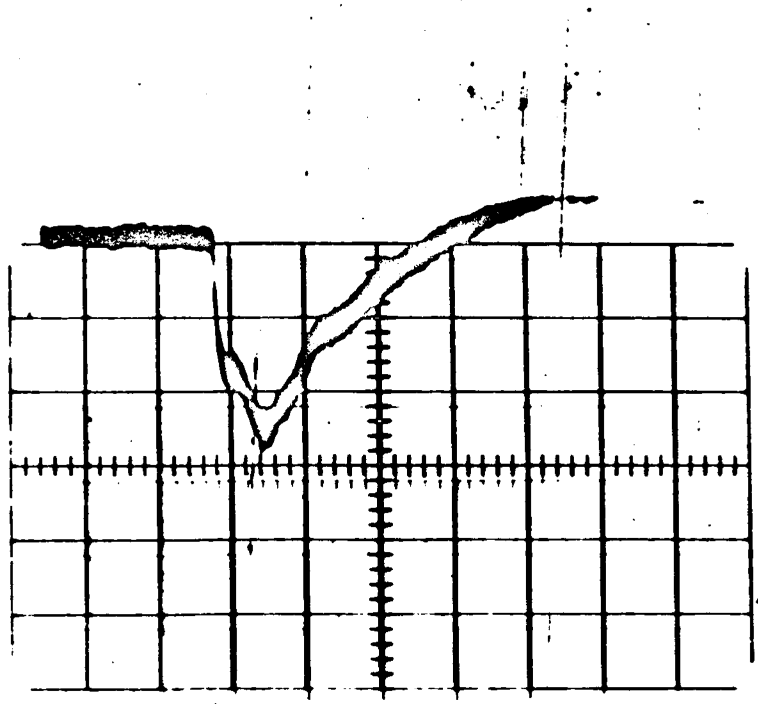
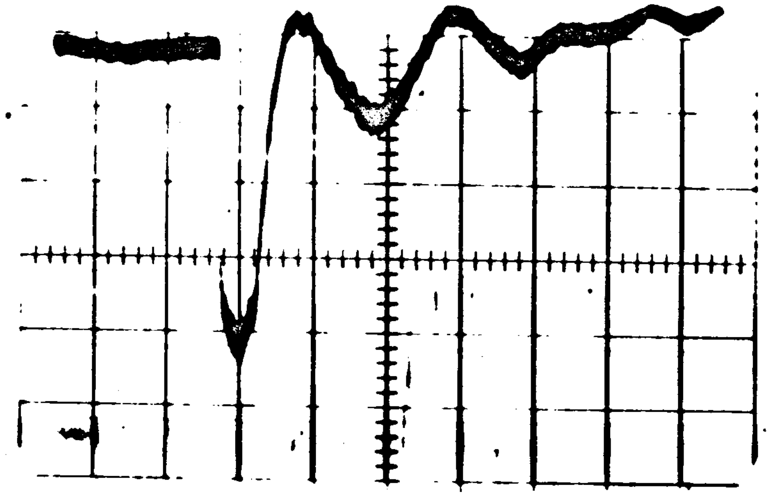


68

5-2



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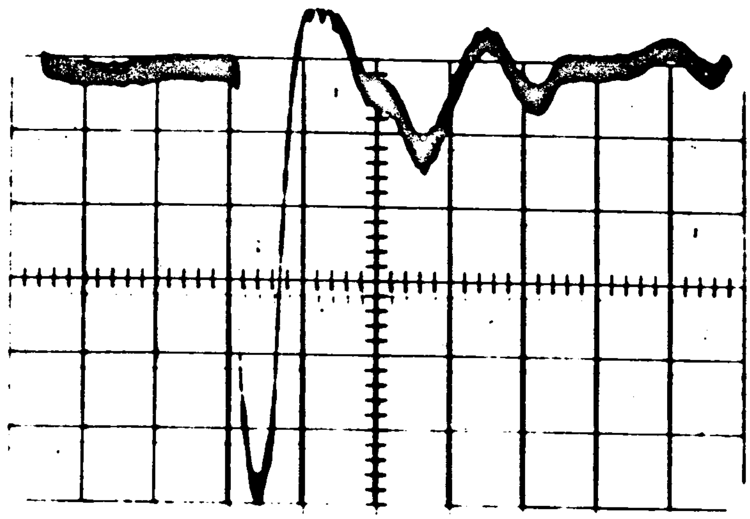

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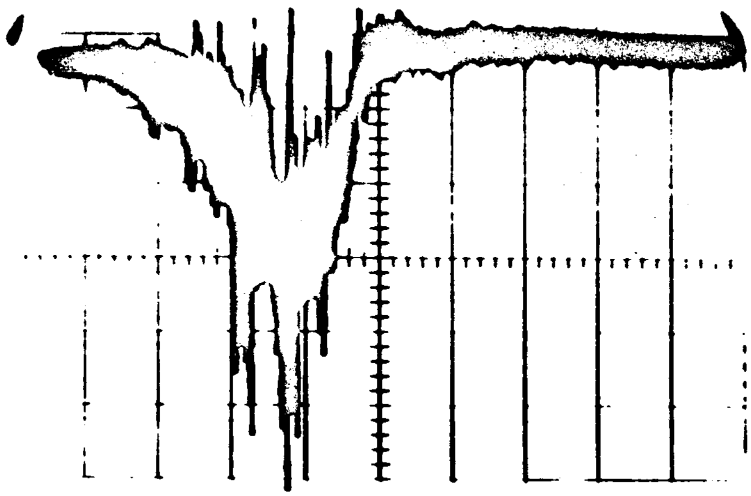

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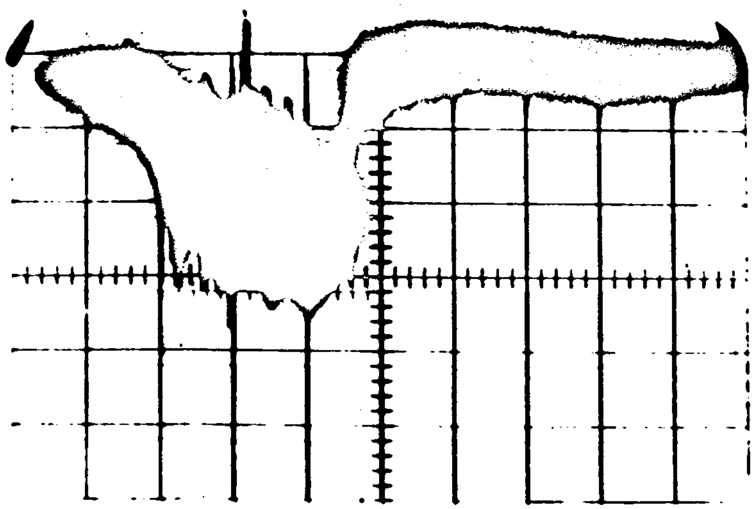

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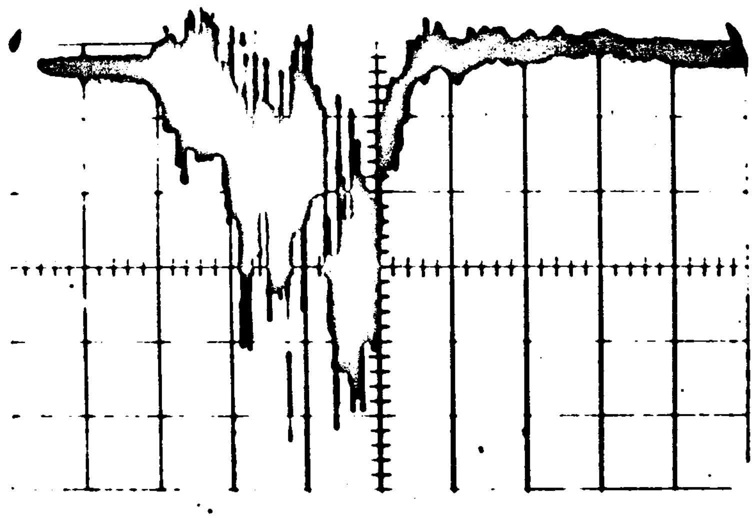

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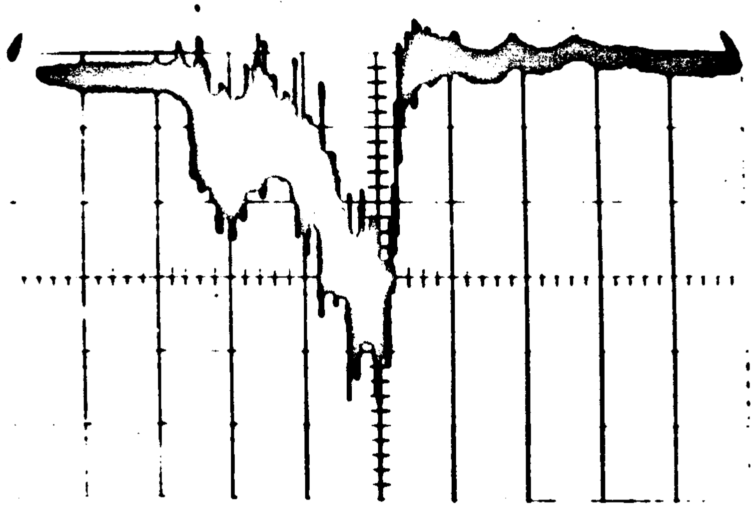

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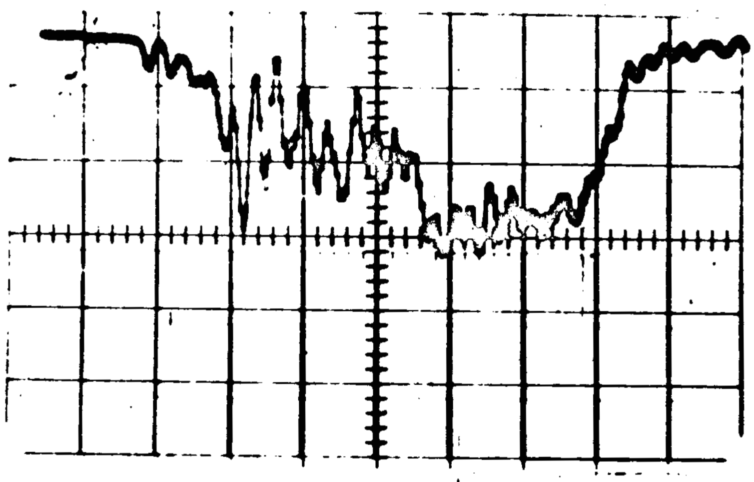

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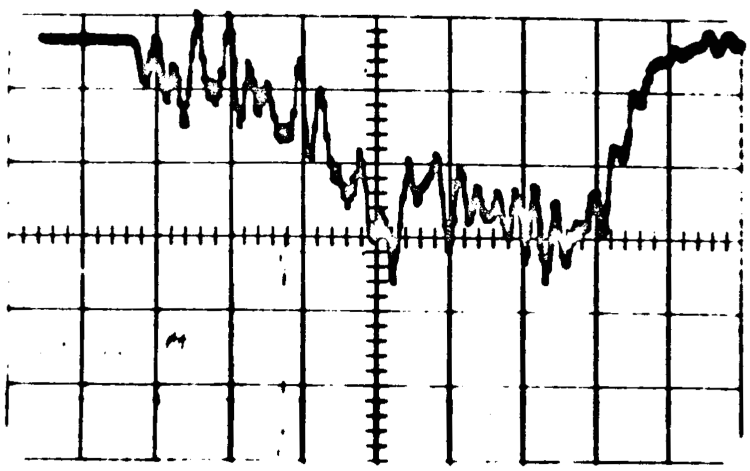

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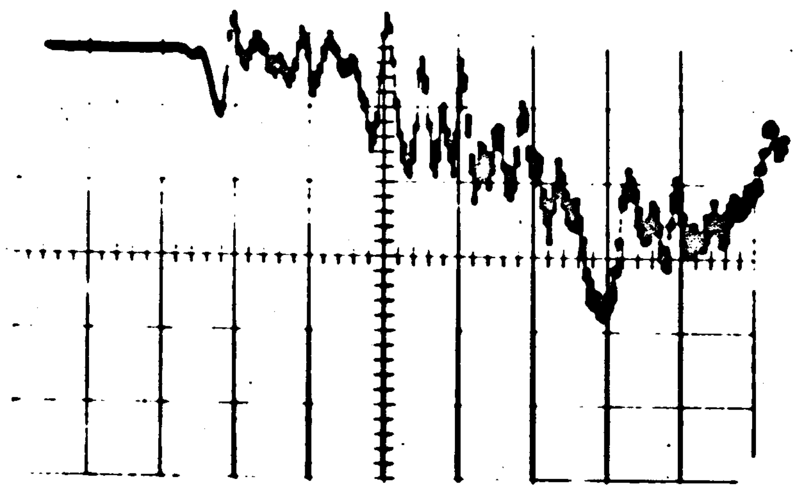

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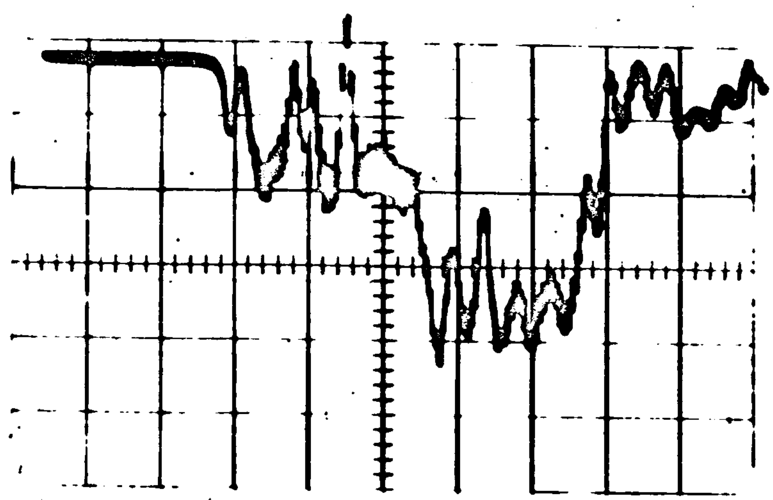

78

Variable temperature

Figures 79-84 show that the penetrometer is relatively insensitive to temperatures from -60 to 125°C.

Device No. ________

Accel. Ser. No. DA58

Accel. E_s 34.0 peak mv/peak G

Circuit C_t 30.4 pf (measured)

Vert. Sens. = .4714 RMS Cal. Voltage

Date 2/1 and 3/62

Observer W. L. Hall

System $E_s = C_t \times E_s \times 2.4 \times 10^{-3}$ mv/G

= 2.48 mv/G

Scope G Sens. = Vert. Sens. ÷ System E_s

Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Temp. °C	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
79	Gum Rubber	3	-65	x		53.95	25.43	10.25	1.0	6.12	5.09	62.7	5.09		—
80										6.07	5.03	62.2	5.03		
81	Gum Rubber	3	Room	x		53.95	25.43	10.25	1.0	6.11	4.86	62.6	4.86		
82										6.05	4.88	62.0	4.88		
83	Gum Rubber	3	125	x		53.95	25.43	10.25	1.0	5.96	4.89	61.1	4.89		
84										6.05	4.92	62.0	4.92		

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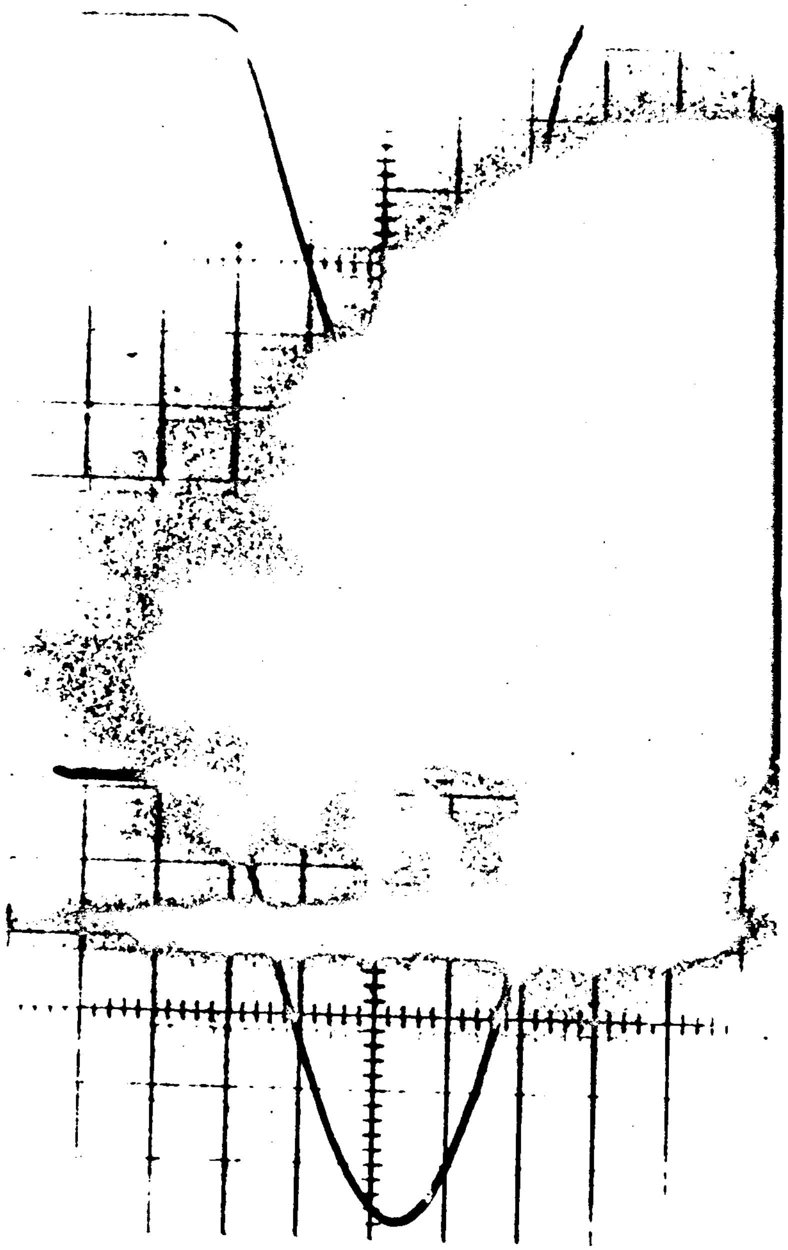

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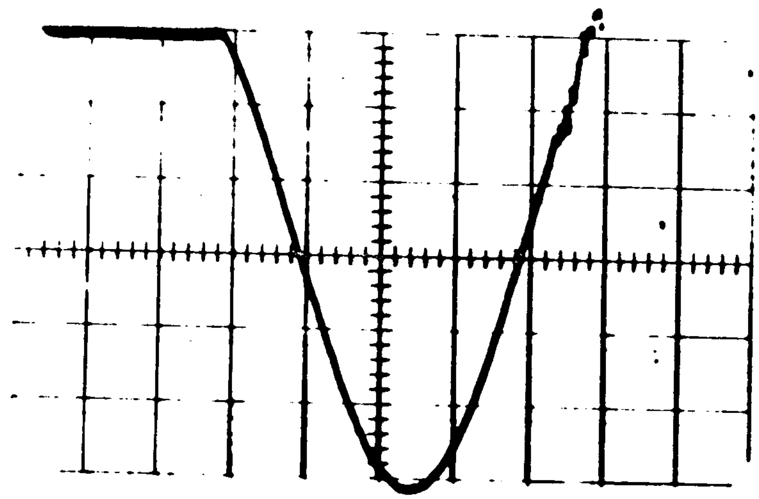

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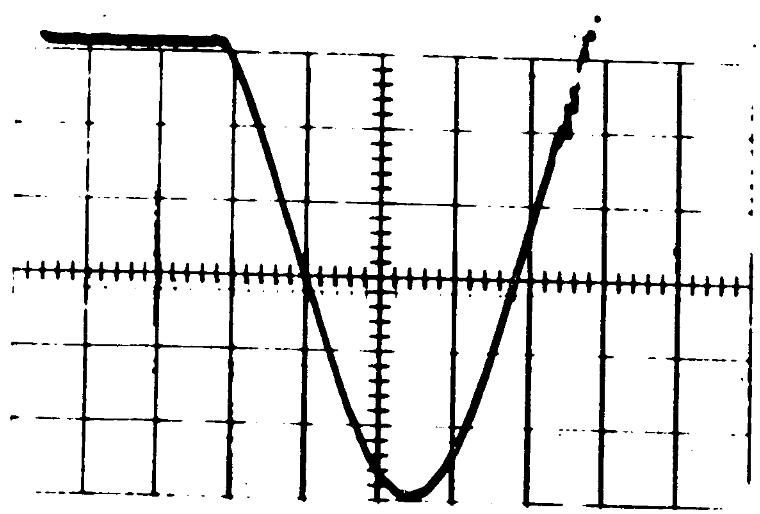

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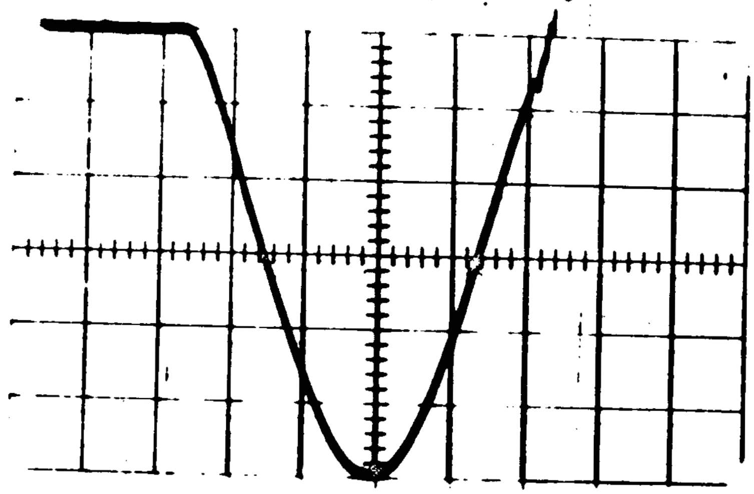

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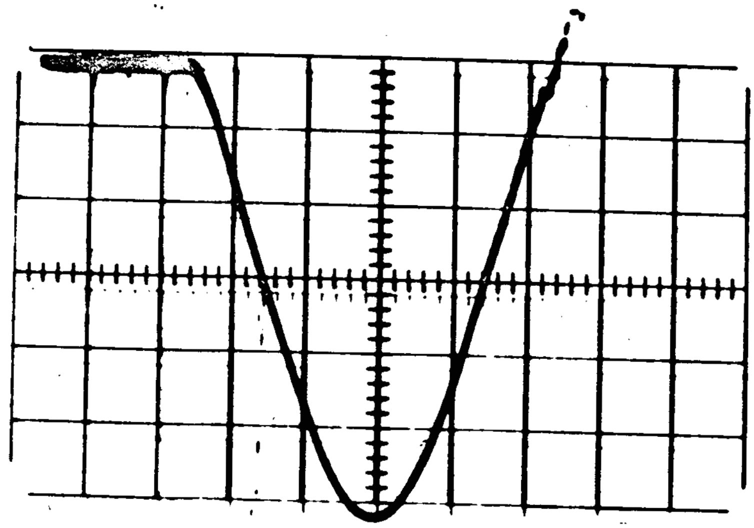

84

Comparisons

The results of the comparison tests of different accelerometers are shown in Figures 85-110. These are compared to Figures 7-14 and are tabulated on Table 1.

Table 2 shows the results obtained on some of the same materials run for calibration.

Expressing the maximum variation (max. to min.) as a percent of the average of all values to get a band width gives the following values:

	Pulse Height	Pulse Width
Gum Rubber	3.9%	0.8%
Lead	3.9	4.8
Aluminum	9.1	4.4
Mild Steel	5.0	5.1
Mild Steel (equally weighted accelerometers)	6.6	7.5

There is certainly no reason to believe that equally weighted accelerometers should give a greater spread than unweighted ones. There may have been enough variation in hold-down force to give the excessive scatter.

Note in Table 1 that the G values given by the DA60 accelerometer are lower than those of the other two in each case. This is certainly indicative of a possible decrease in sensitivity of that accelerometer. This same trait was exhibited by the calibration tests on these same three accelerometers (see Table 2) except that it reads high on mild steel. Again this adds to the suspicion that the hold-down force may not have been closely enough controlled.

Device No. ______

Accel. Ser. No. DA59

Accel. E_s 34.0 peak mv/peak G

Circuit C_t 29.5 pf (measured)

Vert. Sens. = .4714 RMS Cal. Voltage

Date 2/1/62

Observer W. L. Hall

System $E_s = C_t \times E_s \times 2.4 \times 10^{-3}$ mv/G

= 2.42 mv/G

Scope G Sens. = Vert. Sens. ÷ System E_s

Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Temp. °C	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
85	Gum Rubber	3	Room	x		53.95	25.43	10.51	1.0	5.93	4.87	62.3	4.87		
86										5.90	4.87	62.0	4.87		
87	Lead	3	Room		x	129.8	61.19	25.28	.2	6.16	5.09	156	1.02		
88										6.02	5.20	152	1.04		
89	Aluminum	3	Room		x	277.3	130.7	54.02	.1	5.89	4.23	319	.423		
90										5.86	4.27	317	.427		
91	Mild Steel	3	Room		x	599.5	282.6	116.8	.05	6.28	4.43	734	.221		
92										6.36	4.31	743	.215		

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Device No. ________ Vert. Sens. = .4714 RMS Cal. Voltage System $E_s = C_t \times E_s \times 2.4 \times 10^{-3}$ mv/G

Accel. Ser. No. DA60 = 2.34 mv/G

Accel. E_s 32.5 peak mv/peak G Date 2/1/62 Scope G Sens. = Vert. Sens. ÷ System E_s

Circuit C_t 30.0 pf (measured) Observer W. L. Hall Note: G units refer to earth G's

				Tip		Oscilloscope				Measured		Calculated		Standard	
Fig. No.	Material	Drop Ht. Inches	Temp. °C	Sphere	Cone	RMS Cal. Voltage mv/6cm	Vert. Sens. mv/cm	G Sens. G's/cm	Sweep msec/cm	Pulse Height cm	Pulse Width cm	Pulse Height G's	Pulse Width msec	Pulse Height G's	Pulse Width msec
93 94	Gum Rubber	3	Room	x		53.95	25.43	10.87	1.0	5.55 5.54	4.84 4.84	60.3 60.2	4.84 4.84		
95 96	Lead	3	Room		x	129.8	61.19	26.15	.2	5.74 5.78	5.19 5.27	150 151	1.04 1.05		
97 98	Aluminum	3	Room		x	277.3	130.7	55.86	.1	5.27 5.32	4.27 4.25	294 297	.427 .425		
99 100	Mild Steel	3	Room		x	599.5	282.6	120.8	.05	5.92 5.91	4.20 4.20	715 714	.210 .210		

65

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Device No. ________ Vert. Sens. = .4714 RMS Cal. Voltage System E_s = C_t x E_s x 2.4 x 10^{-3} mv/G

Accel. Ser. No. ________ = ________ mv/G

Accel. E_s ________ peak mv/peak G Date 2/1/62 Scope G Sens. = Vert. Sens. ÷ System E_s

Circuit C_t ________ pf (measured) Observer W. L. Hall Note: G units refer to earth G's

Fig. No.	Material	Drop Ht. Inches	Accel. Ser. No.	Tip: Sphere	Tip: Cone	Oscilloscope: RMS Cal. Voltage mv/6cm	Oscilloscope: Vert. Sens. mv/cm	Oscilloscope: G Sens. G's/cm	Oscilloscope: Sweep msec/cm	Measured: Pulse Height cm	Measured: Pulse Width cm	Calculated: Pulse Height G's	Calculated: Pulse Width msec	Standard: Pulse Height G's	Standard: Pulse Width msec
101	Mild Steel	3	DA58		x	599.5	282.6	114.0	.05	6.59	4.35	751	.218		
102										6.55	4.32	747	.216		
103		3	DA59		x			116.8		6.45	4.21	753	.210		
104										6.47	4.20	756	.210		
105										6.55	4.21	765	.210		
106										6.58	4.25	768	.212		
107		3	DA60		x			120.8		5.95	4.14	719	.207		
108										5.98	4.17	722	.209		
109										5.96	4.40	720	.220		
110										6.01	4.46	726	.223		

(All accelerometers weighted to 34.33 gms)

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TABLE 1

COMPARISON OF PENETROMETER TESTS ON STANDARD
TEST SAMPLES WITH THREE ACCELEROMETERS AT 3-INCH DROP HEIGHT

	Pulse Height, G's			Pulse Width, msec		
	DA58	DA59	DA60	DA58	DA59	DA60
Gum Rubber, Spherical Tip	62.2	62.3	60.3	4.84	4.87	4.84
	62.6	62.0	60.2	4.83	4.87	4.84
Lead, Conical Tip	156	156	150	1.06	1.02	1.04
	154	152	151	1.01	1.04	1.05
Aluminum, Conical Tip	324	319	294	0.442	0.423	0.427
	325	317	297	0.437	0.427	0.425
Mild Steel, Conical Tip	751	734	715	0.218	0.221	0.210
	747	743	714	0.216	0.215	0.210
Mild Steel, Conical Tip	751	753	719	0.218	0.210	0.207
(equally weighted accelerometers)	747	756	722	0.216	0.210	0.209
		765	720		0.210	0.220
		768	726		0.212	0.223

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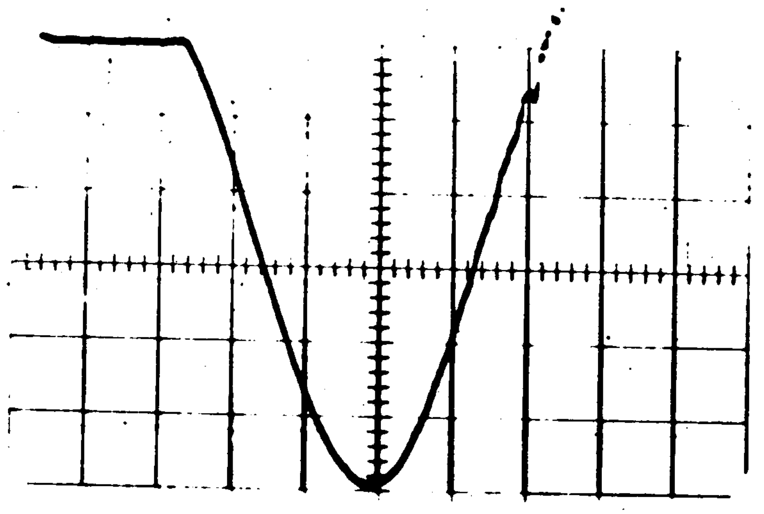
TABLE 2

PARTIAL RESULTS OF PENETROMETER CALIBRATION TESTS
Run 1/29/62-2/3/62
(Data not shown in this report)

	Pulse Height, G's			Pulse Width, msec		
	DA58	DA59	DA60	DA58	DA59	DA60
Gum Rubber, Spherical Tip	62.6 62.0	62.6 63.1	59.9 59.3	4.86 4.88	4.89 4.90	4.86 4.85
Aluminum, Conical Tip	318 325	314 319	303 304	0.435 0.425	0.540 0.530	0.427 0.420
Mild Steel, Conical Tip	718 719	774 771	771 771	0.224 0.224	0.242 0.241	0.236 0.239



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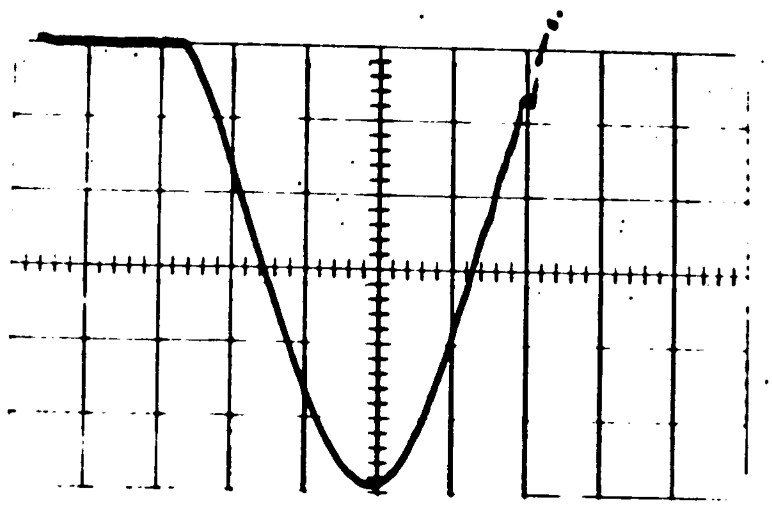

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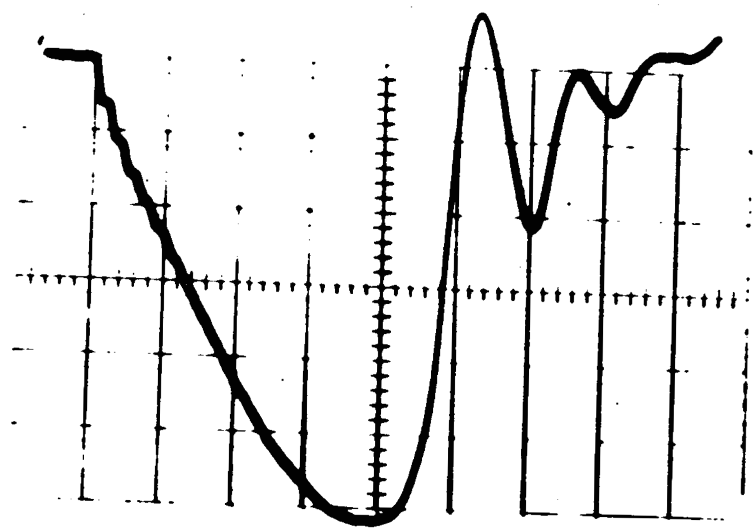

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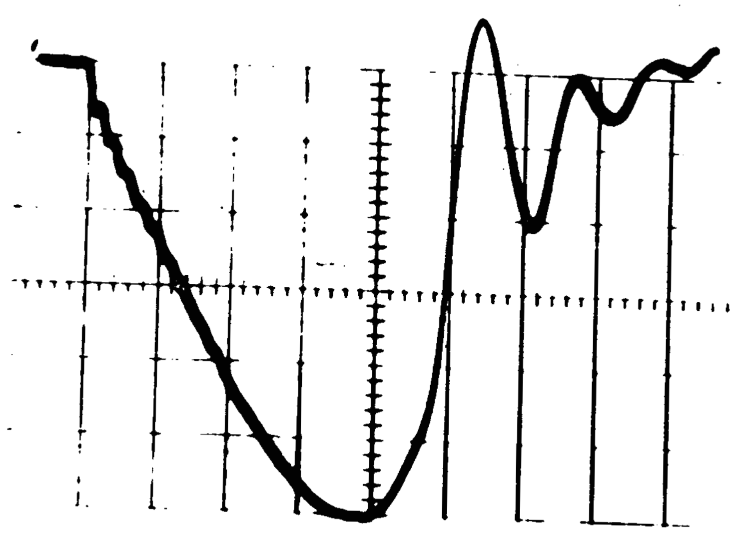

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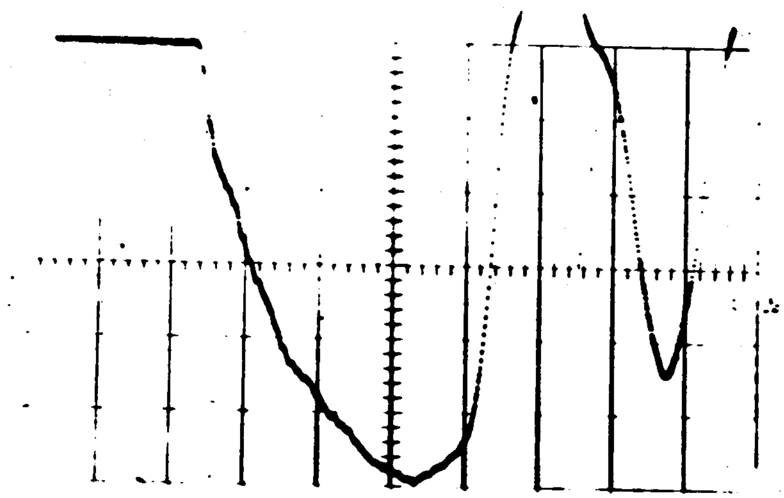

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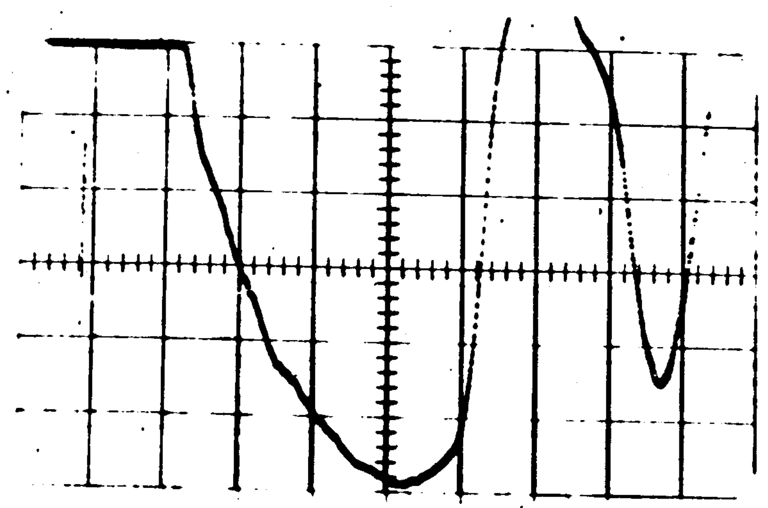

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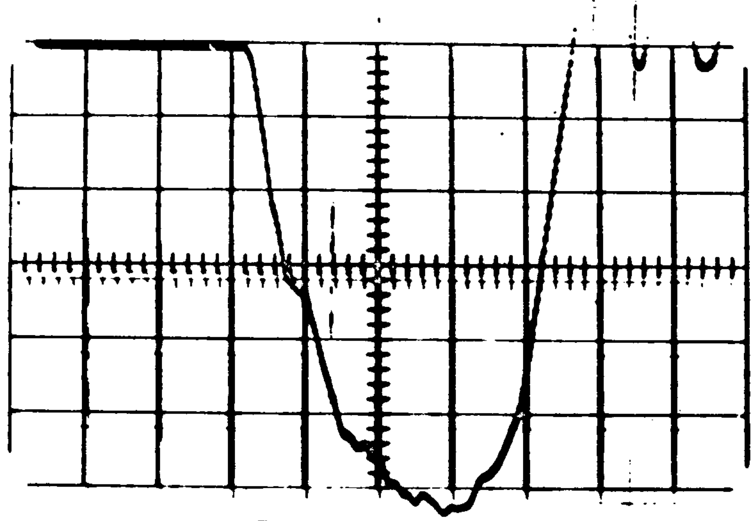

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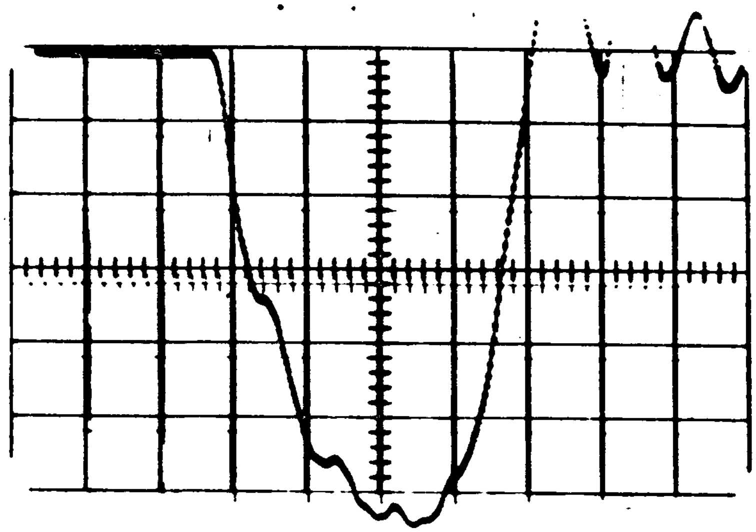

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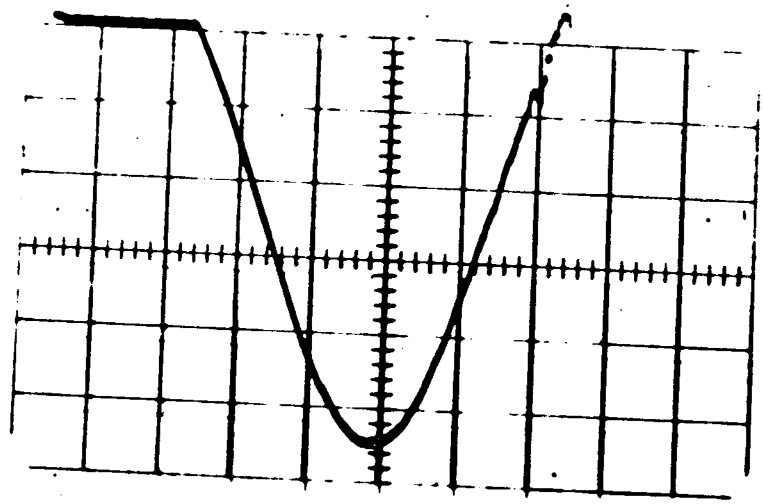

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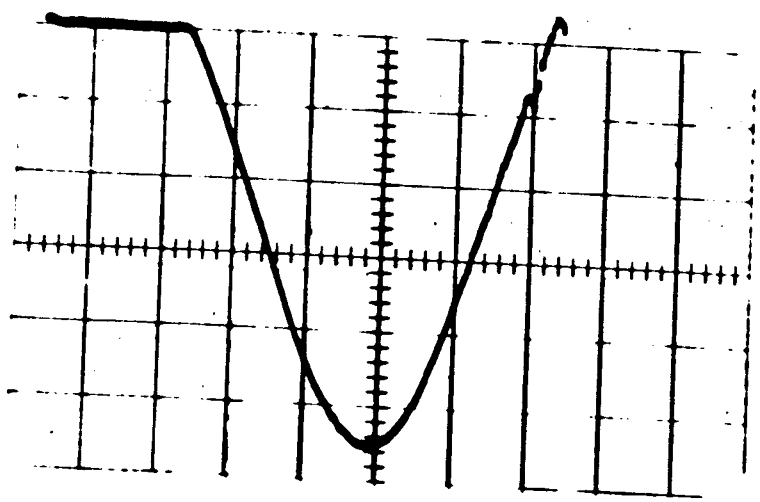

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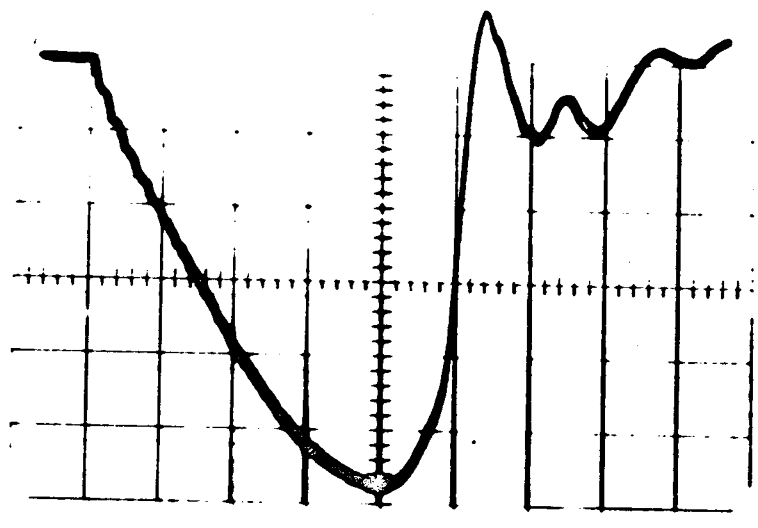

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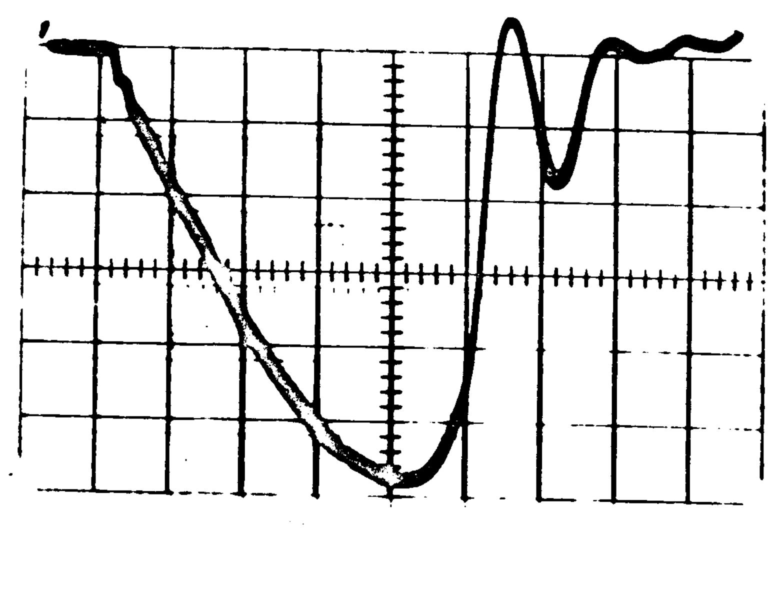

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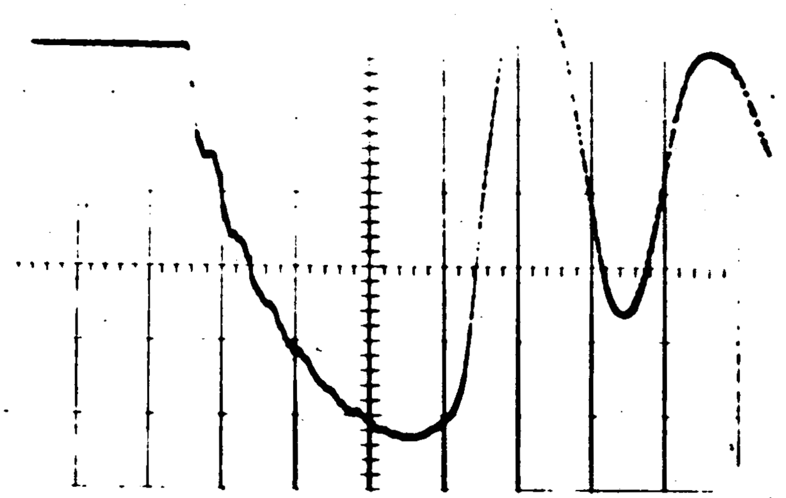

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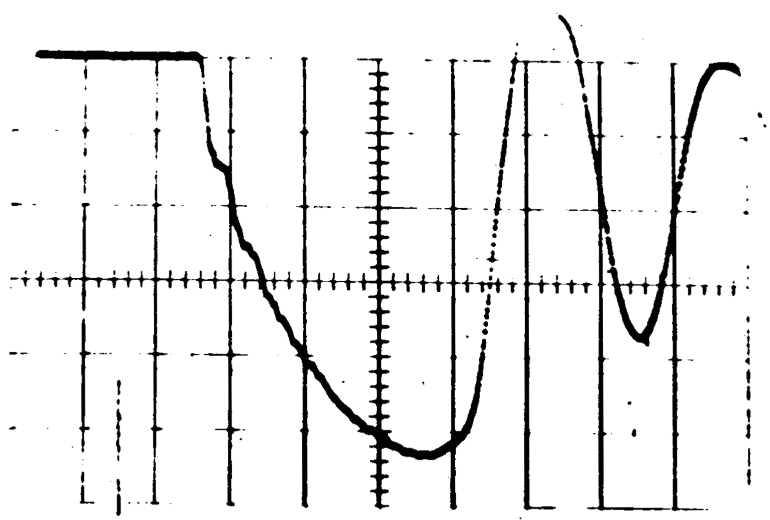

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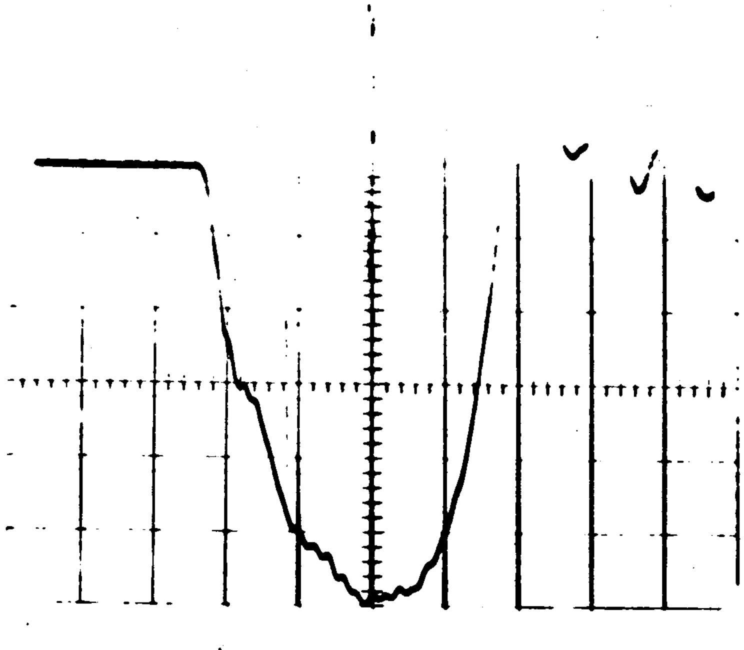

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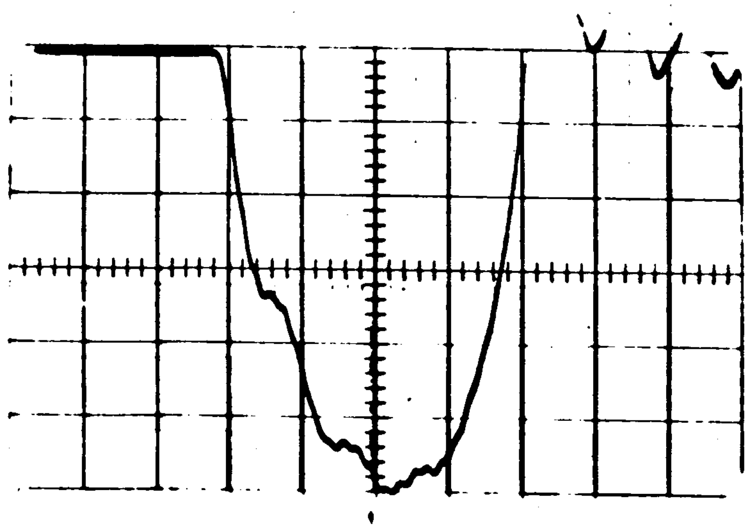

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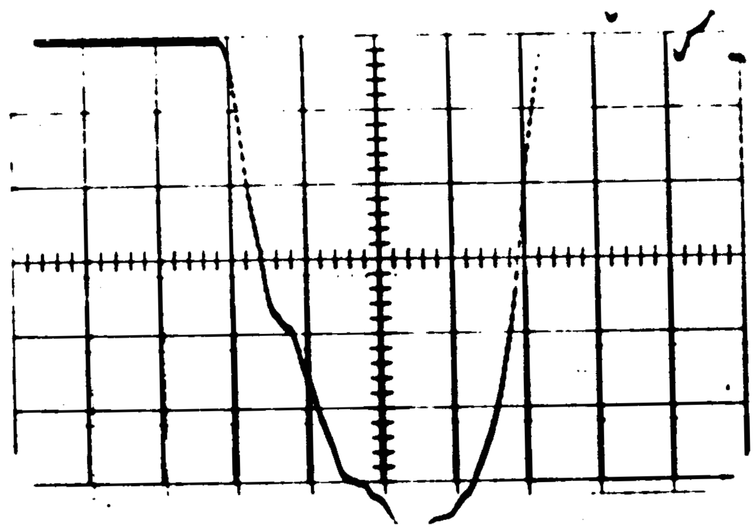

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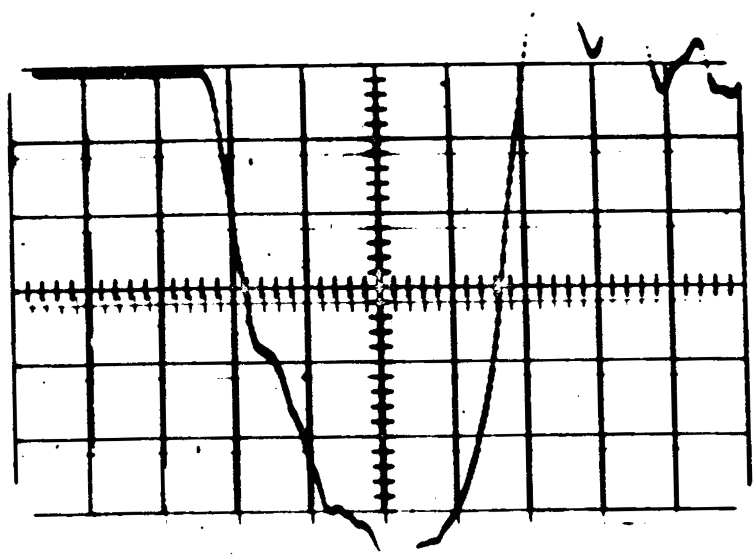

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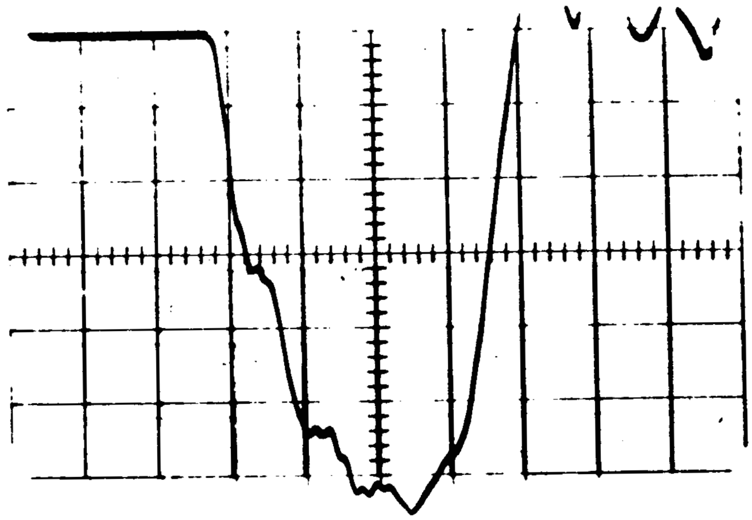

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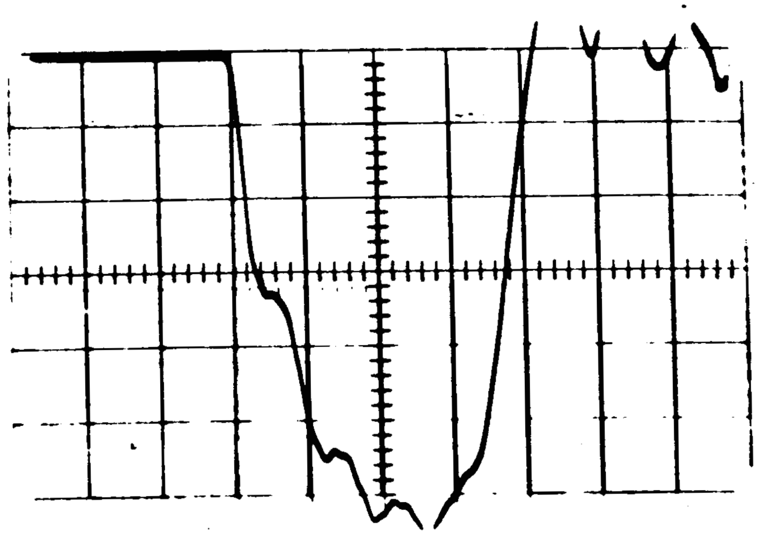

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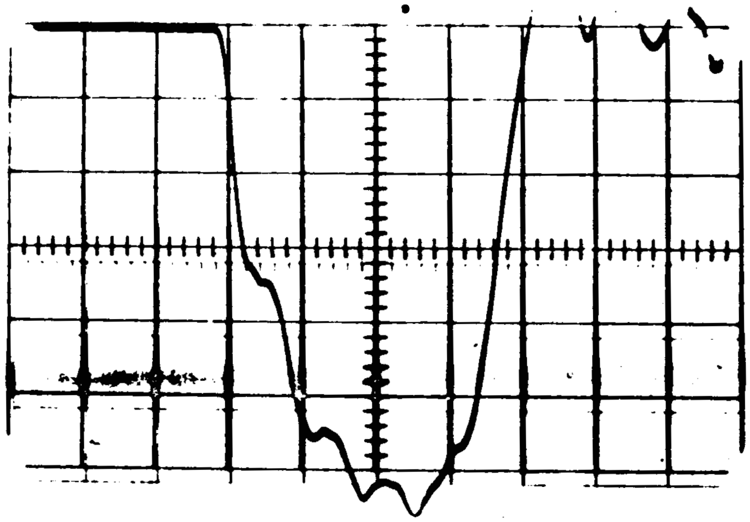
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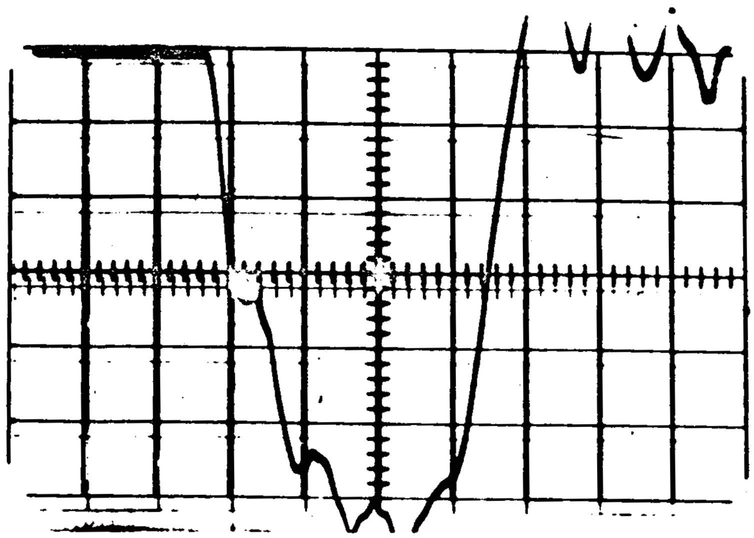
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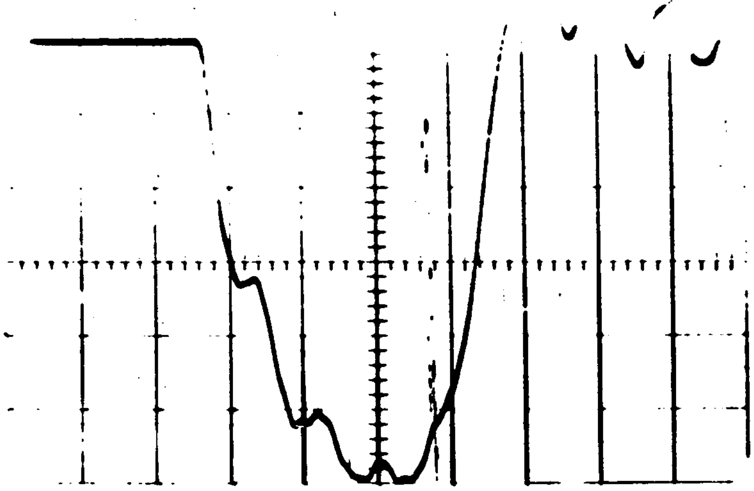

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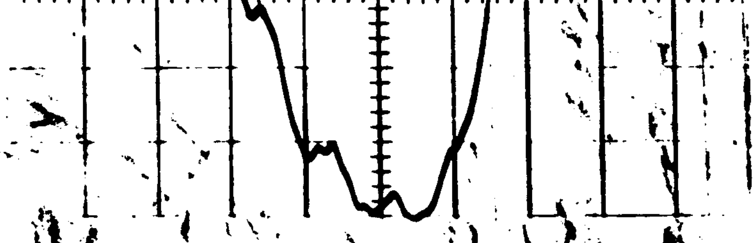

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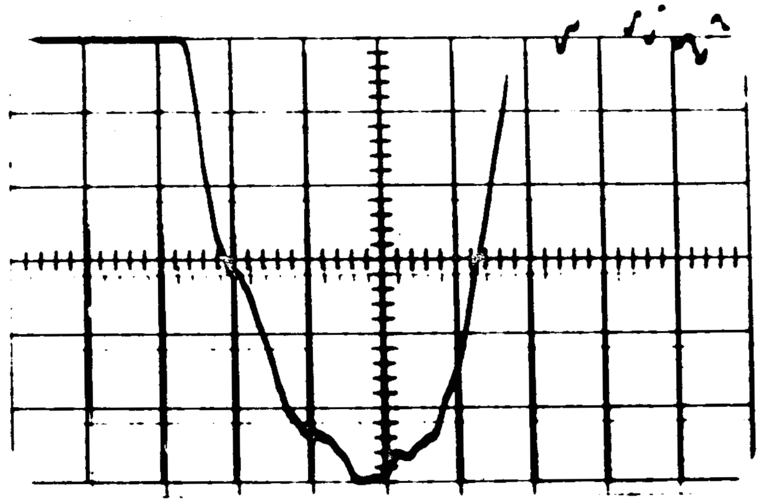

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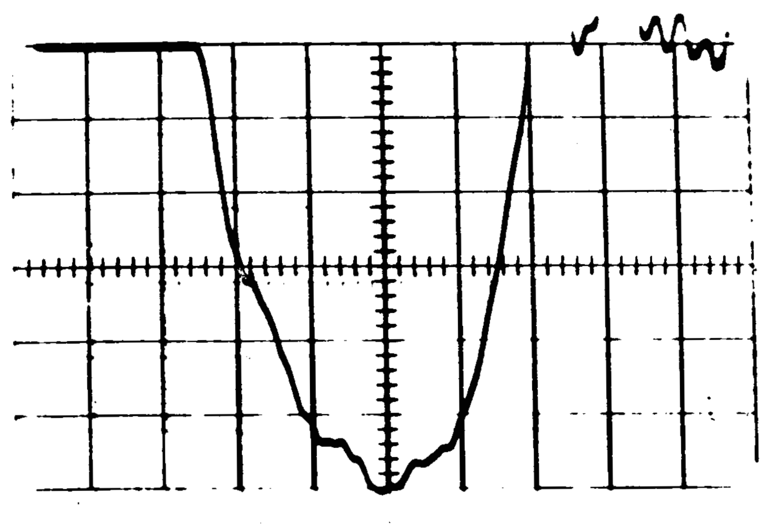

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Remarks

There is little doubt but that the penetrometers tested here can perform their required mission. We would suggest, however, that:

(1) the three accelerometers be returned to Endevco Corporation and recalibrated with the studs now on them,

(2) the effect of variation of hold-down force on the harder test samples be investigated, and

(3) the matter of the clipped signals be pursued, with consideration being given to the advisability of further desensitizing the accelerometers.